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STEEL RAILS FOR PRESENT SERVICE; THEIR MANUFACTURE AND THEIR FAILURES.

By Dr. P. H. Dudley, N. Y. Central R. R. Co.

Presented May 18, 1908

It was a quarter of a century last April (1908) since I completed and submitted to the New York Central and Hudson River Railroad Company, the design for the first 5 in. 80 lb. steel rail for service in the United States. My track inspection mechanism had been in service four years and as complete as at present for two years. I had taken several thousand miles of diagrams of the surface undulations in the track, with a large number of sections of rails ranging from 52 to 67 lbs. per yard and from 3½ to 4½ inches in height. I had made repeated inspections over the tracks of the Philadelphia, Wilmington and Baltimore, the Boston and Albany, and the New York Central and Hudson River railroads. I had also run over the tracks of the Boston and Maine, Eastern, Lake Shore and Michigan Southern, Baltimore and Potomac, and portions of the Pennsylvania railroads.

The autographic diagrams on a scale of one inch in length of paper to fifty feet of track with the surface—vertical—undulations full size, indicated the action and behavior of the various sections under the wheel loads of the mechanism of all the important foreign and American brands of rails. The finish of each was different, and in a short time I could recognize the principal brands from the diagrams, as we passed over the track. The data collected for analysis and interpretation of facts, from the different sections and railroads, included a great range of conditions of operation and maintenance and was of more value than could have been obtained from a single railroad. It soon become evident from the diagrams and the figures of the combined mechanism for summing the undulations into feet and inches per mile, what the trackmen could do with the sections in the track and quite as important what were their limitations. Railroad officials expected at first on those portions of the track which were found below the standard desired, that more labor, ballast or cross-ties would correct the deficiencies and render the entire track uniform per mile.

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Repeated tions after such improvements by labor and material, with t change of rails, still gave evidence of characteristic condition of the steel per mile and while the general track was improved by the higher standard of maintenance, those features pertaining to the steel and sections were not eliminated. This was a new fact for consideration and elicited extended discussion.

I recall reporting to a Railroad President, who was interested in the track inspections and investigations, that the instruments indi- d a few miles of new rails laid the preceding year, had minute es in the surface, but which he considered hardly probable. He said, however, "if you can prove that you have interpreted the indications correctly, I will have the rails replaced." A steel straight edge confirmed the character of the indications, and it was necessary only to make plaster casts of the surface of portions of a few rails, which he could have in his office for examination, to convince him that the interpretations were reliable.

The rails were replaced by those having a smoother finish with decided improvement in the surface and riding of the track. The early steel sections out-wore six to ten of the iron rails they replaced and enabled the railroad companies to reduce the excessive cost of operation and maintenance incident to the daily breakage and failures of the iron rails. The cost per ton of the steel rails contributed to the retention of the limber sections in the track which permitted the concentration of the major portion of each wheel load in passing to every successive cross-tie, the latter abrading and crushing under the rail seats.

The fishing depths of the sections were low and inadequate, the joint fastenings inefficient, and the rails in a short time acquired permanent sets in the tracks which I classified under three principal forms.

The First Form was where the joints were low and the centers high.

The Second Form, the joints and centers were low and the quarters high.

The Third Form, the surface was a series of short waves called "kinkey" by the trackmen.

There were often combinations of the First and Third, and of the Second and Third. The static wheel loads were augmented by the wheel effects—dynamic shocks—once or twice what they should have been, incident to the low joints and irregular surface of the rails with a consequent high train resistance.

The driving wheel loads had increased but little upon the light steel rails, over the practice upon the iron sections. The expended tractive effort had been augmented a few per cent in the American 8 wheel locomotives, but the steam generating capacity was inadequate for the essential requirements of through express trains. Moguls and consolidation locomotives were being used for freight service on lines with heavy gradients.

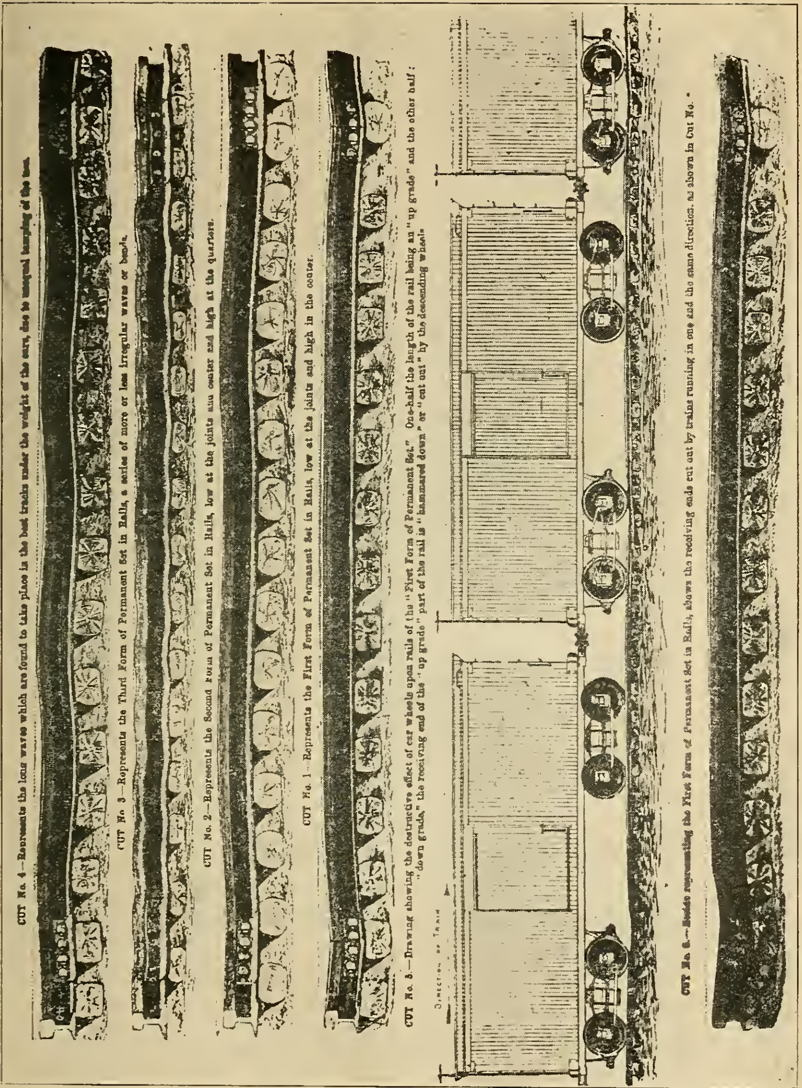

CUT No. 4—Represents the long waves which are found to take place in the best tracks under the weight of the cars, due to unequal tamping of the ties.
CUT No. 3—Represents the Third Form of Permanent Set in Rails, a series of more or less irregular waves or bends.
CUT No. 2—Represents the Second Form of Permanent Set in Rails, low at the joints and center and high at the quarters.
CUT No. 1—Represents the First Form of Permanent Set in Rails, low at the joints and high in the center.
CUT No. 5.—Drawing showing the destructive effect of car wheels upon rails of the "First Form of Permanent Set." One-half the length of the rail being an "up grade" and the other half; "down grade," the receiving end of the "up grade" part of the rail is "hammered down" or "cut out" by the descending wheels
Direction of Train
CUT No. 6.—Besides representing the First Form of Permanent Set in Rails, shows the receiving ends cut out by trains running in one and the same direction, as shown in Cut No.

FIG. I.

Different forms of Permanent sets in light rails.

The light steel rails did not admit sufficient driving wheel loads, combined with the effect of the expended tractive effort to permit the progress in transportation that a country of vast extent of territory required for its development.

It was not alone weight, but augmented mechanical properties of a rail section in the track which would allow the development desired. The road beds were of ample strength to double or treble their tonnage provided the moving wheel loads were distributed in passing to a longer portion and greater area of the road bed. The stiffer rails would relieve each individual cross-tie of as great weight as it received under the lighter rails by distributing a greater percentage in the wheel spacing.

Railway officials riding in my Track Indicator Car, became convinced that the most economical way to increase the stability and capacity of their tracks was to replace their light and limber sections with rails possessing greater mechanical properties, of stiffness and strength.

Officials who did not ride over their tracks in my car were equally as positive that the increased cost of the proposed heavier section would be greater than the benefits to be derived. Good and sound criticism is the most valuable aid a worthy project can have. I was able to point out the fallacies of each criticism to the satisfaction of the New York Central officials who would be directly responsible for the installation of the stiffer section. A 5 in. 80 lb. rail requiring only 23 per cent. more of metal to secure a gain of 66 per cent. in stiffness and 40 per cent. in strength over the former 65 lb. rail was a valuable and economical engineering structure, to increase the stability and capacity of the track. The most optimistic estimates of the benefits of the stiffer rails in the track were less than the realized results, in the progress of transportations.

The 5 in. 80 lb. section was rolled in April, 1884, and laid in the tracks the following July. Mr. J. D. Hawks, Chief Engineer of the Michigan Central R. R., made a 5 in. 80 lb. section which was put in service in 1886. President Roberts of the Pennsylvania Railroad, riding over the 5 in. 80 lb. rail on the New York Central R. R., observed and inquired what it was, and ordered his engineers to design a 5 in. 85 lb. section for their service. The former round topped 4½ inch sections had given the trackmen so much trouble in rolling out and spreading the gage, that it required the cross-ties to be adzed and the rails rolled in, each winter, and they were positive that the 5 in. rails could not be held in the track.

My explanations to the supervisors was, that I had considered that feature and had made the head broad, with a 12 in. top radius, to make the passing wheel treads hold the rails in vertical position, was hardly credited until after thorough trial. When the supervisors found that their tracks with the broad topped, stiff rails kept the gage even without braces on the curves, and also remained in surface for a longer time than the former 4½ in. rails, they saw they were being encouraged and aided in their efforts to secure high standards of track.

The stiff and stable track with the 5 in. 80 lb. rails, enabled Mr.

Wm. Buchanan in 1889 to design the first 100 ton passenger locomotive for service in the railway world. It commenced to run in April, 1890, and Nov. 30, 1891, the "Empire State Express" was installed, the educator for high speed trains for all railway countries. The activity and development of the use of stiff sections of rails, in the meantime, had been great, for American railway officials are quick to perceive and apply principles which achieve results. In 1892 the first 100-ton locomotive started its high speed runs on the first 100-lb. rails.

The stiff sections of rails, as girders, have permitted a development of locomotives until those of 125, 150 and even 160 tons weight, with an equivalent increase of tractive power are common. The freight car capacity also, has increased from 10 to 50 tons, while the freight train load, according to the topographical features of the lines, has been augmented four to six times in tonnage.

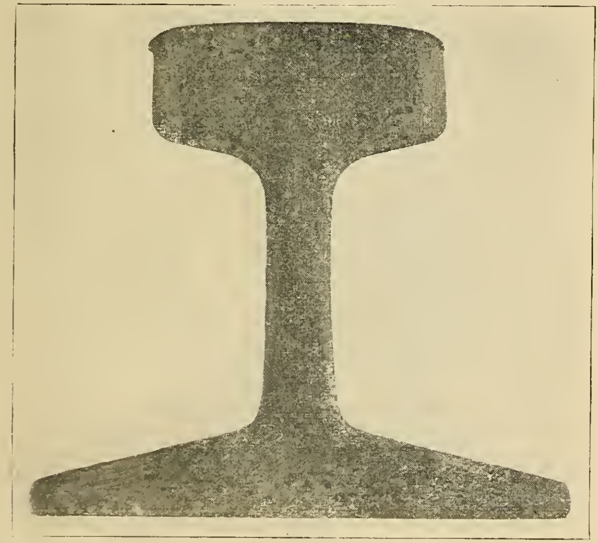


FIG. 2.

B. & A. R. R.—95 lb. rail of 0.60% Carbon and 0.06% Phosphorus.—"Bethlehem." 1891—16 years' service under heavy traffic. Some segregation of the Carbon, indicated. A good rail.

The work the metal must do on the bearing surface to receive, carry and then distribute the heavier wheel loads through the section to the cross-ties, ballast and road bed, is of necessity greater than occurred in the light and limber sections. The bending moments are greater but with less deflection of the rails, cross-ties, ballast and road bed. The records of my work in the past show that I recognized the necessity of increasing the physical properties of the metal, as the mechanical properties of the sections were augmented, and from 1890 to 1900 I made over 600,000 tons of rails of 0.60%, or over, in carbon, according to the section, the phosphorus being confined to 0.06%, or under.

The work that I was able to do between the dates mentioned when cupola-metal was used for steel making and care taken in the composition, shows by actual experience in the track, that sound ingots have been made in which piping is the least of their defects. This can be repeated in larger ingots with the advance in metallurgical knowledge of today.

I made 95 lb. high-carbon, low phosphorous rails from 14 in. ingots at the Bethlehem Steel Co.'s Works for the Boston & Albany R. R. in 1891 and 1892, and gave 5 to 6 min. in the ladle for the oxidation products to escape from the chemical reactions of the recarburizer. The 75 lb. rails for Dr. Webb's Mohawk and Malone railroad were also made at the same time. Those high-carbon, low-phosphorous rails were rolled while Mr. John Fritz was General Superintendent of the plant, for he was the only manufacturer who admitted at that time that such rails could be made. These were premium rails, and the late Mr. William Bliss, President of the Boston & Albany R. R. paid $2 per ton additional for the high grade of steel, and Dr. Webb also paid the same premium for part of his rails. Mr. Bliss considered it economical to secure as good material in his rails as possible, and their services after 17 years, most of them being still in the track, has proven the wisdom of the undertaking.

Prior to this time Mr. Fritz had constructed his 48 in. blooming-train for 16 in. and larger ingots, but it cracked the skin of the ingots so much more than the former 26 in. blooming-train, that as I had my choice of which size of ingots to use, I chose the 14 in. ingot, which made 2 lengths of 30 ft. rails, while the 16 in. ingots made 3 lengths of rails.

The Boston & Albany rails were of 0.60% in carbon and down to 0.06% in phosphorus, as were also a part of the Mohawk & Malone rails. The molten steel after being recarburized in the converter, was poured and remained in the ladle from 5 to 6 minutes, to allow the chemical reactions and oxidation-products to escape, before teeming the ingots; these were stripped, then thrown down in the pits and charged into horizontal furnaces for equalizing the heat before blooming. The 26 in., 3-high blooming-train of 11 passes was used, and the blooms were cropped until sound steel was obtained, then chipped under the steam hammer, and again charged into horizontal furnaces for reheating and then rolled in 11 passes into rails. They were finished between 950 deg. C. and 1,000 deg. C., as nearly as could be measured by the Siemens copper ball and water pyrometer. We had not then advanced to the scientific requirements of sawing the rails 0.01 in. shorter for each second of time after leaving the roll and rolling so cold as to frequently damage the rail as a girder. Rolling the rail cold, for wear, is one factor to be considered, but this in any case must not exceed the safety-factor as a girder. The new type of rail sections with 0.5 in. thickness of edge can be rolled too cold for safety, as had occurred in some experiments. The Bethlehem rails, on the Boston & Albany R. R., after 16 and 17 years' service on heavy grades and sharp curvatures, have lost only about ⅛ in. in height, from the large volume of traffic which has passed over them. These rails were not lettered to show from which part of the ingot they came, but walking over the track it can be readily seen which were the rails from the top of the ingots. The fractures of these rails, both on the Boston & Albany and the Mo-

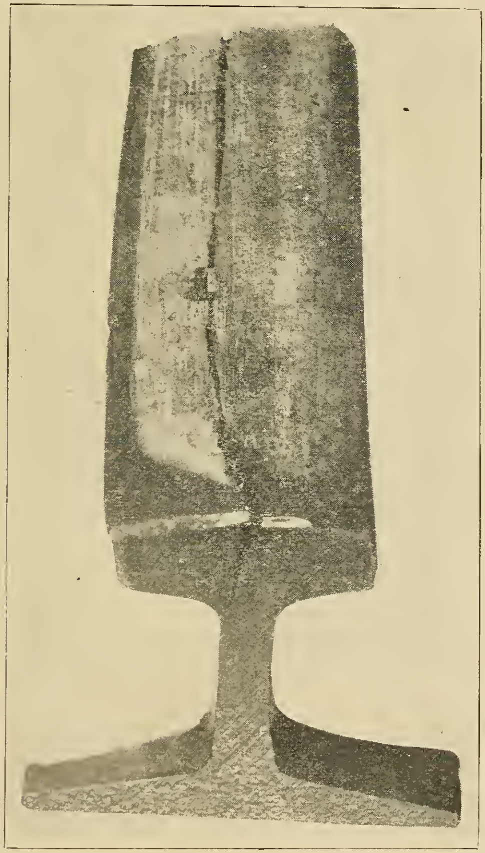


FIG. 3.

B. & A. R. R.—95 lb. rail, Bethlehem, 1891.—Failed Jan., 1908. Supported at joint by 20 in. angle bars of 0.10% Carbon, which were soft and wore rapidly. The rail head flattened and split from insufficient support, rather than from inferior metal.

hawk & Malone railroads have been exceedingly light after so many years of service. They have excellent wearing properties and are also tough as girders.

More than 600,000 tons of rails of my sections were rolled at Scranton, Pa., with carbon of 0.60% and phosphorus of 0.06%. These were rolled from 14 in. ingots of sufficient length for three—30 ft. rails. Special efforts were made to secure a composition which would set well in the ingots and be free from pipes. The number of "stickers" which were broken under the drop were sufficient to show the general soundness of the ingots.

DEFECTS OF INGOT STRUCTURE.

Pipes, as shrinkage cavities or from slag inclusions from the recarburizer, or from vessel slag which accidentally gets into the ingot molds, are well known facts, though pipes due to shrinkage cavities are best known.

Minute blow holes often occur in the sides of the ingots and frequently are numerous in the central core. The latter are generally surrounded by segregated elements of carbon, phosphorus, sulphur and silicon.

The chemical composition should serve two important functions:

1st, to provide the basis for the physical properties desired in the steel.

2nd, to secure sound ingots. This requires the adjustable feature of the composition used in making the high carbon and low phosphorous rails.

The exhaustion of the low phosphorous ores requires the use of phosphorus at 0.10% and the carbon for 100 lb. rails for service where the temperature falls to 20 or 30 degrees below zero Fah. should not exceed 0.45 or 0.50%. The silicon can be from 0.10 to 0.15% with the manganese at about 1% for ingots of a length of about 2½ times the width of base. Sound ingots can be made by holding the steel after recarburizing in the converter, 2½ to 3 minutes or about the same time in an intermediate ladle before teeming. The latter has been the practice at the Illinois Steel Co., South Works, for some years and the benefits are well established. The nozzle in the ladle should not exceed 1½ in. or at most 2 in. in diameter, and the metal be poured in a solid stream, to avoid spattering the molds, and carrying quantities of air in with the steel.

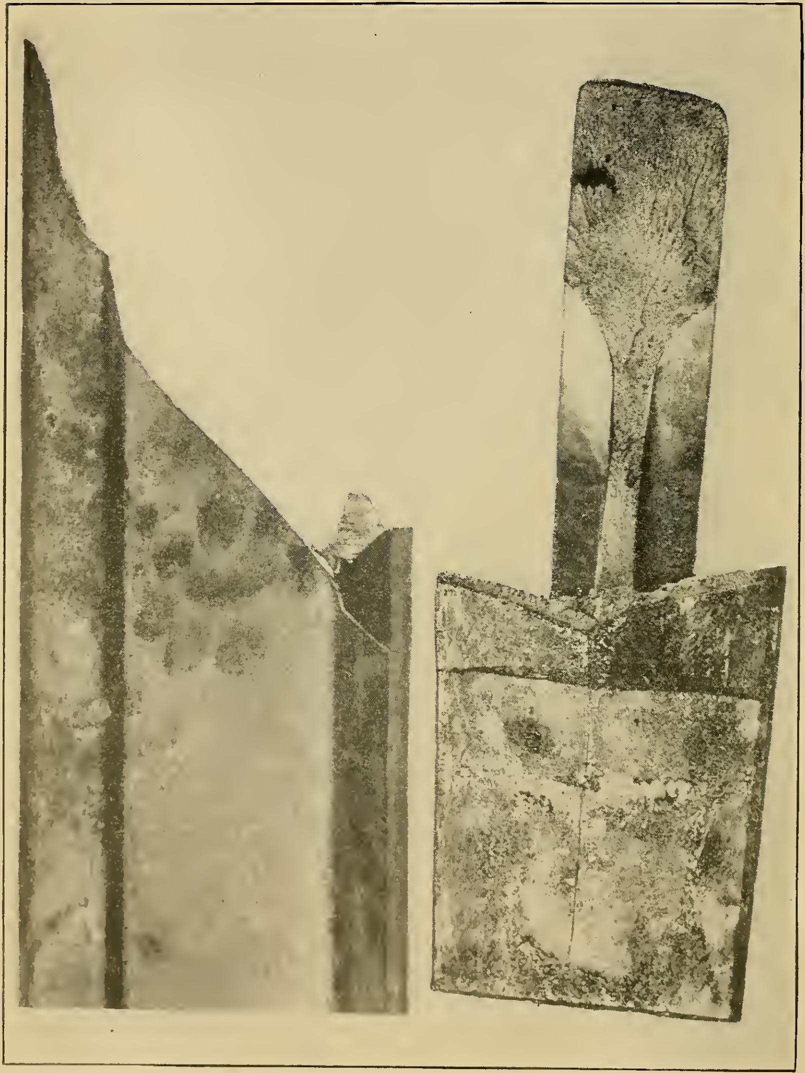
The columnar structure in the corners of the upper part of the ingot will entrain traces of slag and gas which will appear as defects in the heads of the rails after more or less service. The upper part of the ingot will have a well defined central core inside the columnar structure of the ingot.

To study the defects of ingot structures besides those due to pipes, I commenced lettering the rails A, B, and C, as rolled from the top, middle and bottom of the ingot for the New York Central and the Boston and Albany railroad companies in December, 1892, at the Lackawanna Iron & Steel Co.'s plant, Scranton, Pa. The rails contained 0.06% in phosphorus and 0.55 to 0.60% in carbon for 80 lb. rails and 0.60 to 0.70% carbon for 95 and 100 lb. rails. These rails after 12 to 16 years' service have developed but comparatively few base fractures, which were nearly equally divided between the letters. Out of over 500,000 tons, only 20 piped rails, in the webs and heads, have been found to date, though there is about one-fourth of one per cent. of split heads, which are common to all of the letters. There is a slightly greater percentage of defective rails in the letter A than in either the B or C rails. These rails were all made from ingots which were cast in the pits and as soon as they were stripped, thrown down into a horizontal position, then loaded upon the ingot trucks and charged into horizontal heating furnaces. The chemical composition was adjusted to make a sound ingot, the metal carrying from 0.6 to 0.8% of copper. Many of the ingots as "stickers" were broken under the drop to see the solidity of the metal, and it was rare to find a central cavity of ⅛ in. in diameter in any of the ingots after they were cold. The rails are giving a slow rate of wear and only near the inside running edge of the upper corner of the head of the A rail, for about one-third of its length, do they show the slight inclusions of gas or slag in the structure of the upper part of the ingot.

The B and C rails rarely show any defects. The letters can be found on most of those now in the track. The "New York Central Lines" have been restencilling a number of rails with white paint, indicating by the letter so that persons can examine them and see the different rates of wear between the A, B and C rails. The A rail usually wears slightly faster than the B or C. Rails which have been in service 16 to 17 years and have carried from two hundred and two hundred fifty millions of heavy tonnage, have lost only from 1-16 to 1-8 of an inch in height in the center of the head, while those on the curves show but little flange wear. The effort in making those rails was to secure a slow rate of wear by a chemical composition and not by cold rolling, as is proposed at the present time. But few half-moon breaks in the base have occurred in these rails after their long service.

COLD ROLLING.

It is not generally understood that steel for rails, can be rolled too cold during their manufacture. It is found by experience that cold rolled rails, which have been manufactured extensively since 1900, break to a greater extent in the tracks when the temperature falls to zero or below, than the rails which were rolled at the ordinary working temperatures. The cold rolling is beneficial for the rate of wear in the head, but when the rails are rolled at near or below the "critical temperature" for the steel, it is detrimental to the rail as a girder. The base, web and head may be chilled and hardened so that the ductility is decreased, for the ordinary chemical composition of the section, and they are injured under the straightening press.



FIGS. 4 AND 5.

Shear over the supports of Drop Testing Machine. Under the drop test, the shear is usually curved or inclined and more than in the track. The two triangular fractures in the base of rail are due to reversing the bending of the edges as occurs under the gags of the straightening press.

The half-moon breaks, which have occurred over the cross-ties in the rails of the past four or five years manufacture, are generally associated with cracks or seams in the base. These may be due to cracks in the skin of the ingot in blooming, inclusions of silicates of manganese, or laps from the passes, or ragging. Many consider that these are the primary causes of the fractures. The more recent physical examinations of broken rails show, that associated with these seams, the metal is usually brittle, having been chilled in rolling. The flange cracks easily under a light blow of the sledge. The fractures can in many cases be traced directly to the initial strains in the metal due to "gagging" in straightening the rail at the time of manufacture. The edge of the base of the rail on one side will check from the bottom upwards, and in an inch or two from that, the top of the flange may check from the top downward.

These are detailed progressive fractures even though completed under a locomotive or train, and usually when found some part of the fracture had previously oxidized or discolored, showing it had been days, weeks and sometimes months in developing.

The gagging in such cases was sufficiently severe to put reversed bends in the edge of the base and had left decided initial stresses in the metal at the junction of the base and web and in the flanges due to permanent sets of the metal in straightening the rails. The majority of the half-moon or crescent shaped fractures occur on the top of the cross-ties, and finally rising through the web and head, as a vertical shear with slight curvature through the web. Comparing these fractures with those which occur over the supports of the drop testing machine, they are found to be identical except as to the length of the curve, as the rail shears over the support. Increasing the thickness of the base for colder rolling than has been before considered permissible, does not check the tendency of the metal to fracture in the edges of the base under the reversed strains of the gagging process. The cold rolling reduces the ductility, the same as though greater additions were made of carbon or phosphorus. The fractures in the base of the cold rolled rails are not confined to the letter A, representing the top of the ingot, as is generally understood, but are distributed through the entire rails of the ingot and in a few cases have been identified as confined to a single ingot of the heat. Out of 201 specimens of broken rails, 43 were A, 46 B, 33 C, and 18 D rails. The latter form the smallest percentage of any of the letters in the track, for the reason that in long ingots they generally make the most seconds and are rejected as second-class rails. There were 61 rails out of 201 specimens in which the letter had become so oxidized as to prevent identification. The A rails formed about 21 per cent. of the letters identified, the B 22 per cent, the C 18 per cent, and the D about 9 per cent.

The base failures I have described are those of my observation under high speed trains where the temperatures were 20 to 30 degrees below zero Fah. for several consecutive days. The winter of 1906 and 1907 had the longest protracted periods of low temperatures. in many localities that the weather bureau has yet recorded, and I did not see more than one or two direct tension breaks, all of the fractures being developments of injuries, strains or defects in manufacture, coincident with the combined cold and heavy service. These are technical problems for the rolling mills and the railroads to investigate and solve.

The low temperature has two effects upon the ordinary Bessemer steel rails: First, to raise the elastic limit and increase its fragility under shocks. Second, to set up thermal stresses due to contraction before the ends of the rails slip in the splice bars.

Each fall in temperature of one degree Fah. sets up a stress of 200 lbs. per square in. of the area of the section where the ends of the rails are held firm. The friction of the splice bars per lineal in. of the 80 lb. rail of my sections, is 4300 to 4400 lbs., and for the 100 lb. splice bars it is 4800 to 5000 lbs. One-half of a 36 in. 80 lb. splice bar would hold a tension of 77000 lbs., and the 100 lb. splice bar 86000 lbs. before the ends might slip in the splice bars. The most frequent base breakages are in the periods of low temperatures, and consequently affect the rails laid in cold, more than in warm climates.

HEAD FAILURES.

The numerous split heads in rails of recent years, called by the trackmen "piped rails" and which are found in all brands, occur more in some than in others. When the steel is cast in long ingots, the upper part is not deoxidized as much as the average, and with a well defined exterior envelope not securely connected to the spongy central core. The passing wheel loads cause the metal in the bearing surface to spread laterally and it becomes loosened from the central core underneath. The widening layer of metal eventually checks and splits that of the central core underneath. The surfaces of the vertical split discolor in a short time and are often reported by the trackmen as a flaw or pipe.

There are often one or more minute layers of ladle slag—(silicates of manganese)—from the chemical reactions of the recarburizer, ⅛ to ¼ of an in. under the bearing surface, which permits the metal to spread easily and split the metal underneath, particularly when there are small seams formed by the closing and elongating of small gas bubbles surrounded by segregated metal. The split may develop at the end, but more often occurs in one or two places in the quarters or centers of the rails. It sometimes starts and breaks from one side of the head and develops toward the center and then across to the opposite side.

The spattering of the mold in pouring or when a heat must be pricked, seems responsible for some split heads; but the teeming of the ingots too quickly after recarburizing the steel, containing minute globules of silicate of manganese associated with insufficient deoxidized metal, seems to be a greater factor.

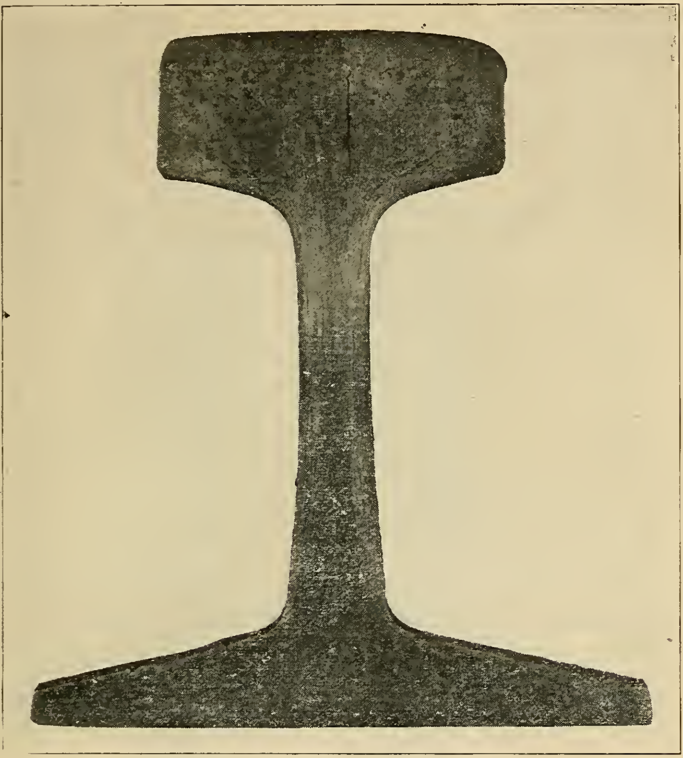


FIG. 6.

N. Y. C. & H. R. R. R.—100 lb. Carnegie rail of 0.45% Carbon and 0.10% Phosphorus.—Split head. Segregated fragile metal forming central core. The envelope of metal, forming the bearing surface for the head is soft, and has the usual expanding wedge over the vertical split in the central core.

The central core of the upper part of the ingot is often a motley collection of segregates in the insufficient deoxidized metal which were rejected by the setting steel of the lower portions of the ingot and entrained before rising to the top. Some of the segregates, as ovoid bodies in the ingots, are drawn out in rolling into long cylinders and form the dark streaks in longitudinal etchings of the rails, while the white streaks are generally carbonless iron. The silicates of manganese as globules, are drawn out into threads in the section of the rails, resulting in a reduction of the solid volume in the heads, particularly when associated with insufficient deoxidized metal. The rapid wear, flow of metal and crushing of the rail ends, are to be expected from such conditions.

Pipes in ingots from shrinkage cavities or inclusions of ladle slag or vessel slag, ganister and split heads, would be "pipes" to the trackmen, but each require a different metallurgical treatment for correction.

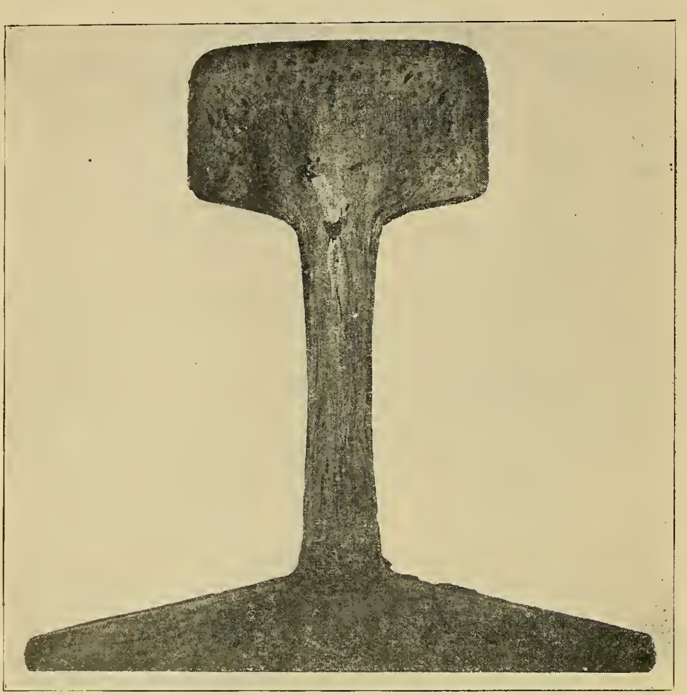


FIG. 7.

100 lb. rail—A. S. C. E. section showing accidental inclusion of ganister. The result in manufacture, or in the track, would be reported as a piped rail. while true in effect it is not due to the shrinkage cavity of the ingot. Its prevention is a mechanical, rather than metallurgical problem.

The consumer is expected to tell the manufacturer when the rails fail, which is but a small part of his privilege and duty; he must investigate and tell the manufacturer the reasons why they fail to meet the conditions of service. Transportation has made such rapid strides during the past two decades on the stiff rails as engineering structures and the demands of the commercial interests for more facilities, so pressing and insistent, that some things have been done to meet emergencies by both the consumer and manufacturer, obliging both to work nearer the upper margin of capacity than would otherwise have been done. Some manufacturers have shortened by one or two minutes the essential time after recarburizing the heats before teeming the ingots, while the consumer has been obliged to increase the wheel loads, expended tractive effort of the locomotives and speed of his trains to a degree only recently considered possible.

Two years ago to suggest to the manufacturer that slag was disseminated through the steel in the rail head, was met by what he considered just indignation as to the correctness of this statement, but when shown to him, he no longer doubts but takes measures for its elimination. The steel manufacturer has to contend with the storms quite as much as the rail user. The atmospheric moisture will not wash out or submerge the manufacturer's plant, but the

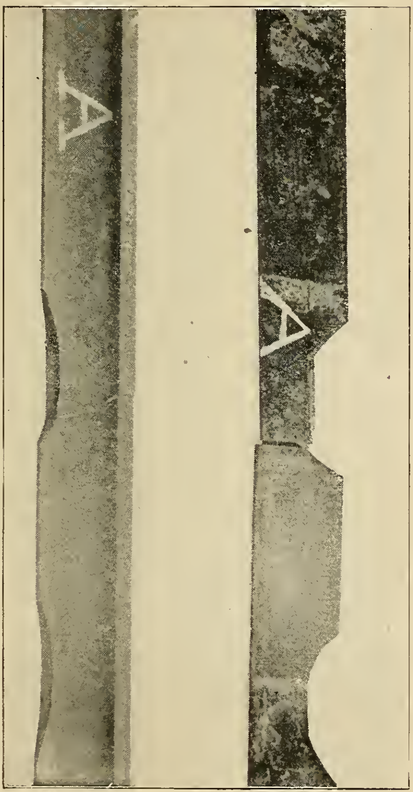


FIG. 8.

N. Y. C. & H. R. R. R.—100 lb. rail—L. S. Co.—1904. Two crescent shaped pieces broken from base of rail. The development of checks or strains under the straightening press in manufacture. One of these checks or strains contributed with seams of manufacture in the base, to its detailed fracture and shear of the remaining part of the section and is typical of rail breakages in cold climates. The check adjacent to the shear of the web started from the underside and also split near the median line of the base, while the opposite end is checked from the upper side of the base. The other crescent fracture checked from the underside of the base.

amount of moisture which in humid weather, will go into the blast furnace will change the character of the product.

The Bessemer converter uses for the conversion of each ton of metal, five to six-tenths of a ton of air, and whether each cubic foot of air contains one, or six to eight grains of moisture is felt at once in the Bessemer department and the rail mill by increased difficulties of manufacture, not easily surmounted.*

It is gratifying for me to find that from independent investigation that the consumer and manufacturer are arriving at the same facts and conclusions from which mutual benefits will result.

DISCUSSION.

Mr. W. H. Finley, M.W.S.E. (Chairman): In the matter of rails —taking the paper just as it was read by Dr. Dudley—I would ask if any better results are obtained by the use of the open-hearth process than have been secured in the past by the use of the Bessemer process?

Dr. Dudley: That is a matter which must be intelligently tried. We shall avoid, by the basic open-hearth process, as much phosphorus as we now have in our present rails, and probably the brittleness will be less, but so far as wear is concerned that is something which will have to be determined by service tests. The brittleness seems to be less in the basic open-hearth steel, unless it runs too high in the carbon or other hardening elements. The metal must be higher in the carbon to get a serviceable rail by the basic open-hearth process, than is necessary in the Bessemer process, with the use of 0.06% of phosphorus. I have seen a number of rails rolled of basic open-hearth steel in which the carbon ran from 0.65% to 0.75% and those rails were tough. However, with a slight increase in carbon running from 0.68% to 0.78%, in an ordinary section, a great deal of brittleness developed, and the rails were not as tough as those with a less amount of carbon.

I made for the New York Central R. R., a few thousand tons of basic open-hearth rails, rolled from three length ingots and branded A, B and C, commencing with the top of the ingot. All the different letters will be observed for wear. We are putting them in a place where we require great toughness. We will have more reliability, so far as brittleness is concerned, than in the ordinary Bessemer rail with 0.10% phosphorus.

Mr. Finley: I think Dr. Dudley ought to be able to give the railroad companies some information as to the road-bed itself. He has spoken in regard to the rail and the effect of the rolling stock on the rail. Doubtless he has observed, in his experience, how the road-bed, the ties, and ballast are affected. Can he suggest anything that would be of benefit to the railroad companies in that respect?

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*The "dry blast" was applied to the Bessemer Converter at the South Works—Illinois Steel Co.—a few days after this paper was read and with beneficial results. P. H. D.

Dr. Dudley: The observations which I have described in detail tonight—the road-bed and ballast—were factors which were taken into consideration. It is necessary to have a well-maintained road-bed, to get the best results so far as the undulations are concerned. The standard of maintenance has improved in the last decade and the tonnage carried is three or four times as great as it was ten years ago. Some of the railroads have 40 to 45 per cent. of the road-bed covered with cross-ties under the heavy rails, but I think such a high percentage is not necessary. There is considerable elasticity to the track and road-bed, which settles from ⅛ to ¼ in. under wheel loads of the locomotives and cars. It is difficult to make that amount of undulation uniform, where stiff rails, with too many ties, are used per rail length. It is almost impossible, in the tests for the unit fibre strains, to get uniform results from the different axles even with the same static loads. We obtain uniform results when we compare the entire stresses from a locomotive or a car; for the single wheel there is wide variation, due to unequal distribution of the load, tamping and ballasting of the track. It is difficult for the trackman to tamp every tie so it will have a uniform bearing. The results show that as a rule, a track well ballasted with stone is maintained for the entire year in a better condition than a gravel-ballasted track, though the latter is easier to surface.

It often takes two years after it has been replaced by stone ballast, for the track to become as smooth as under the gravel ballast. The trackmen must learn how to take care of the track. Many are discouraged at first when replacing the gravel ballast with stone, but after they become experienced, they keep their track in much better condition. The first year or two after the change from gravel to stone ballast, the tracks are somewhat rough and do not ride smoothly. There is much in favor of stone ballast, however, for heavy service; the road-bed should be well drained, which is one of the most important factors; not as much attention has been paid to this as should be in this country. By draining, a firm road-bed is secured, in which the undulations will be uniform.

The breadth of the top of the rail is another important item; it makes a smoother track. The narrow top rail cuts out at the receiving end and makes a noise and shock which the trackmen cannot eliminate. The Belgian Government have just designed a new 117 lb. rail, and have made it even broader than my 100 lb. section; they added ¼ in. to the width. I was disappointed in not finding as smooth riding on these heavy rails as ought to have been secured by the 105 lb. rail. The track was rough in a short time, and they acknowledge that it does not ride as smoothly as they would like to have it; and they do not understand the reason. I think that with heavier rails and less ties we can secure a smooth track with some elasticity which is better than one that is extremely rigid. On many roads it takes only a short time to wear out the 80 lb.

rails, while the 100 lb. rails will carry over 250,000,000 tons, and still be smooth before it is removed. This is due to the difference in the breadth of the rail head.

Mr. J. R. Budd: I would ask Dr. Dudley if he has made any investigation along the lines of rail corrugation?

Dr. Dudley: My broad top rails have little corrugation. One of the first things I noticed in connection with the narrow top rail was that they got rough on the curves. That is one reason why I made the head broader, and corrugation seldom occurs now on any of the broad top rails.

Mr. Budd: What is the cause?

Dr. Dudley: The narrow top rail gets the effect of the ragging of the rolls and develops the corrugation in subsequent service.

Mr. Budd: I have noticed it more on the new sections than on the old 60 lb. rails.

Dr. Dudley: Our 100 lb. rails have entirely too much work in the straightening press; they should receive more hot bed work.

Mr. Budd: The gagging introduces internal strains?

Dr. Dudley: Yes, a great many strains are introduced and after they start, they continue to develop under the wheel loads. On our broad rail head it is different; it does not wear as quickly as the rail with a narrow head.

THE DEVELOPMENT OF THE ELECTRTC RAILWAY

JAMES N. HATCH, M.W.S.E.

Read February 14, 1904.

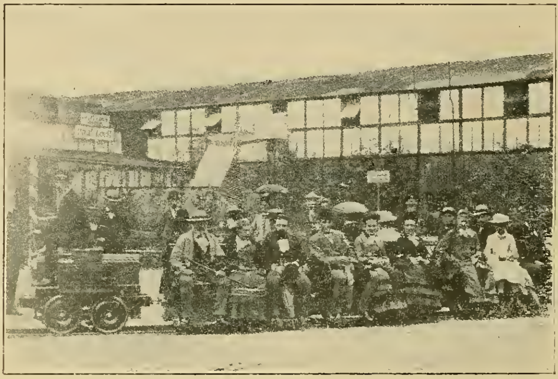
There is probably no branch of modern industry that has exercised a greater influence upon the social organization of this country during the past twenty years, than the Electric Railway industry. This influence began and grew to very important proportions even while electricity was used as a motive power only on the surface cars of our city streets. Even with this limited field of operation, the rapid transit afforded the suburban districts of the cities, made the modern American city a possibility; brought the outlying districts within a few minutes' ride of the heart of the city, and prevented that great congestion which is found in foreign cities. And later, with the advent of the interurban road, this readjustment of the centers of population has become much more pronounced, until the entire population of the United States is feeling the effect of the changed condition. It is not only the city person who has thus gained a great advantage in being able to appropriate the benefits of country life; but the country person is also greatly benefitted by having extended to him the valuable influence and advantages of the city.

The electric railway is thus exerting a great influence in equalizing social conditions and in breaking down the barriers that have always been felt to exist between the urban and the rural civilization of our land.

It is not possible to define exactly when electric traction cars were first invented or to laud one inventor as the originator of the electric car. In fact, the modern electric railway has been evolved from a laboratory toy, and is as we see it today the product of the minds of many men. Each successive inventor has added a little here or a little there, until the result is the successful enterprise which is now coming into so much prominence.

The idea of operating cars by electricity was put into practice, experimentally, more than seventy years ago, but at that time neither dynamos nor motors had been invented and the use of the primary electric battery as the motive power for vehicles was not at all an encouraging problem. Another circumstance that effectually retarded the progress of the electric railway was the success attained about this time by the steam roads, which seemed to solve effectually most of the important problems of transportation. A few experiments were carried on from time to time both in America and in Europe, with battery driven cars, but very little encouragement was found in these attempts. And it was not until after the year 1867, the year in which the dynamo was perfected, that any real progress was made toward a large electric car suitable for the practical carrying of passengers.

Following promptly upon the commercial exploitation of the early magneto—electric and dynamo—electric generators, came a sharp renewal of the effort to perfect the electric railway. But even then it required twenty years of experimental work before any system was so far perfected as to show evidence of real commercial success. It can therefore be said that the modern electric railway is the product of the last twenty years.



Electric Locomotive and Cars first operated on May 31, 1879, at the Berlin Trades Exposition.

However, in the few years that have intervened since a successful system has been perfected, the development of the electric railway has been very rapid and the outlook for the future is stupendous. The electric roads now in operation in the United States would, if collected together, furnish enough trackage to build a ten track line from New York to San Francisco, and the cars in use would, if placed end to end, make a continuous wall reaching from Chicago to Pittsburg. There are more miles of electric road in the United States than there in all the rest of the world put together, and the electric roads in the United States have more mileage than the combined electric and steam roads of any one European country. The present growth represents an equivalent of a new line from Chicago to San Francisco every year.

This growth and advancement from year to year has been little less than marvelous. The average rate of construction for the past six years has been 2,500 miles per year, which represents a growth per annum of more than half of the annual growth of the steam roads for the same period. And this represents practically all new work, for the changing over period had nearly ceased before the year 1900.

With these facts in mind it is not difficult ot believe that the time is at hand when the electric railway must be seriously reckoned with in the financial economics of this country. At the present rate of increase there will soon be a perfect network of interurban lines throughout the entire densely populated portion of the United States. Probably during the present summer, electric cars will run through from Chicago to Louisville and Cincinnati, and it will be but a short time until it will be possibe to go from Chicago through to Detroit and Cleveland on electric cars.

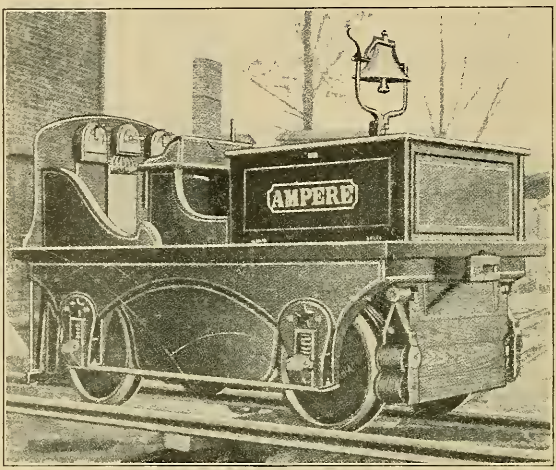
According to the United States census report of 1890, there was in 1886 two electric railways in successful operation, with a combined mileage of eight miles; in 1887 there were four roads with a combined mileage of twenty-nine miles; while in 1888 the business had increased until there were then in operation twenty-nine roads with a combined mileage of nearly three hundred miles.

For a number of years prior to 1886 there had been numerous attempts made to put in operation a successful electric car, and it was confidently believed by the various inventors that electricity was adapted to the propulsion of street railways; yet none of these attempts were so far successful as to supplant the well-established methods of operation with horses or steam dummys. While every attempt which had been made was of inestimable value in forming a stepping stone to better things, some weak spot always developed, that rendered the enterprise a financial failure. But these obstacles, while very disheartening at the time, did not seem to discourage the designers of these early days, but only served to awaken them to the necessity of renewed efforts to perfect the system which they believed destined to be rewarded with success.

As early as 1880 the electric motor had been so far perfected and simplified that the outlook for a practical electric car was encouraging, and a number of designers were in the field working on schemes to make electric traction a success. In 1881 and 1882, Leo Daft began experiments with a commercial size electric car, firm in the belief that it was possible to replace the horse as a motive power for street railway by electric traction. Mr. Daft formed the Daft Electric Co., and made a large number of public tests for the purpose of demonstrating the practicability of the Daft systems of electric traction. This company built an eletcric locomotive which they called the "Ampere," for use on the Mt. McGregor steam railroad at Saratoga, and during the summer of 1883 equipped about 1.25 miles of that road with 35 lb. third rail, mounted on resinized wood blocks in the center of the track, with soft rubber insulation under the foot of the rail and bolt heads. Experiments were continued for two or three weeks with more or less success. One feat of the Ampere is described as hauling an ordinary day coach containing 68 passengers over a curve of about 100 ft. radius up a grade of 93 feet per mile.

Following the Saratoga experiment, the Daft Electric Co. in 1884 built several show lines at Coney Island and elsewhere, to advertise to the people at large the feasability of the system. As an outcome of the Coney Island demonstration, the Daft Co. was awarded a contract for about two miles of actual street railway line in Baltimore.

This was a very trying piece of line to begin with, as there were grades of 350 feet to the mile, and curves of from 40 feet to 70 feet radius, with a gauge of 5 ft. 4.5 inches. The line was owned by the Baltimore Union Passenger Railway Co., and the contract with the Daft Co. was entered into in 1885 and work upon the equipment was started forthwith. Many troubles developed in the installation and subsequent operation of the line, but it was operated with enough success to attract the attention of capitalists and to awaken ambitious engineers to the belief that there was really a power almost within their reach which was destined to revolutionize the street railway business.



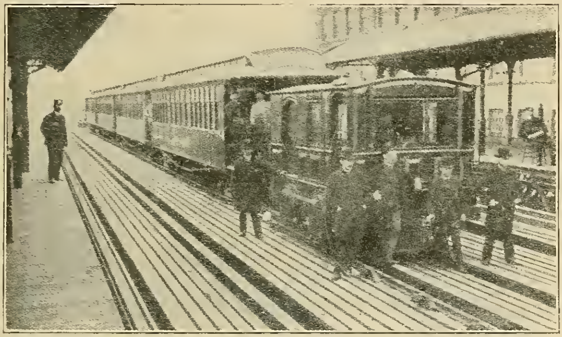
Daft's Motor "Ampere," 1883.

Daft's Baltimore Road.

With this line an electric locomotive hauled the regular street cars. These locomotives or dummys were equipped with motors placed on the floor of the car and the axles of the car were driven by large gears. The track was equipped with a third rail to supply current, placed midway between the track rails, which were used for the return circuit. An overhead trolley was used where long crossings were encountered, and it was in this way that the first trolley system was put into operation.

Daft says of his Baltimore road which was put in operation in 1885, that "therewith the first commercial electric railway in America had hung up its shingle."

This suburban road continued in successful operation until 1889 or until it became part of a network of electric railways which were equipped with more modern apparatus. Daft introduced the double trolley system of electric traction with a trolley wire return. This system is still in operation in Cincinnati.



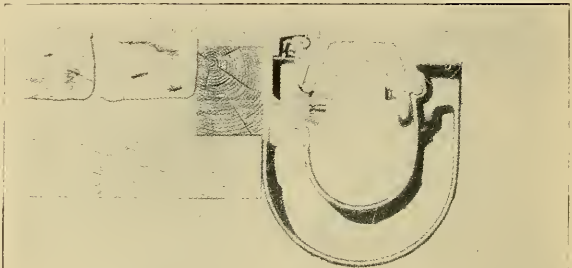
"Benjamin Franklin" of 1887-8 on New York Elevated Railway.

In 1888 Daft placed on trial a large electric locomotive, on the Ninth Avenue Elevated Railway in New York. This locomotive was called the "Ben Franklin" and was placed in service with the hope of showing the advantage of this motor over the steam locomotive then in use. These trials were conducted under a variety of conditions, in an endeavor to convince the most skeptical of the advantages of electric motive power for elevated roads. This motor was able to draw six of the ordinary elevated cars at a speed of forty miles per hour. These experiments were thoroughly successful, but the necessity of changing from steam to electricity did not seem to be apparent at that time, and in fact was not fully realized for a long time afterward.

During the time that Daft was carrying on his early experiments in the east a number of inventors in the west were making experimental efforts to demonstrate other systems of electric traction. One of these early railways which gained considerable prominence, and which was among the first electric railways successfully operated, was that at the Chicago Exposition in 1893. An electric locomotive known as the "Judge" operated for some time during the exposition on an intramural railway, and hauled 26,000 passengers. The Judge was made in accordance with the design of Edison and

Field, who had combined their efforts in electric railway design. The Judge weighed about 3 tons and drew a trail car for passengers.

In the fall of the same year Messrs. Bentley and Knight, who had witnessed the performance of the "Judge" at Chicago, formed the Bentley-Knight Railway Co., and constructed a short experimental electric railway in the yards of the Brush Electric Co. at Cleveland. The results of the experimental line were so encouraging that during the next year this company constructed a line over a mile long in Cleveland, and operated cars with more or less success and constancy for more than a year. This company used the conduit system, in which the conductor was carried in a wooden box placed between the track rails.



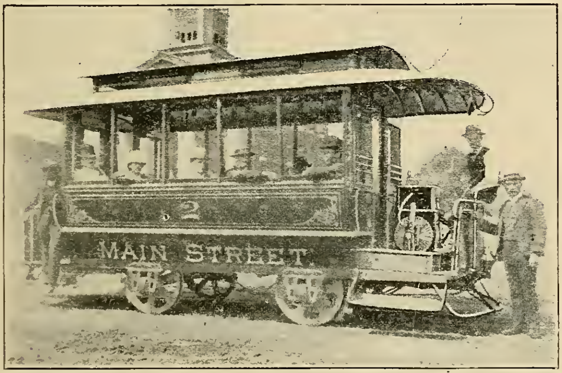
SECTION OF BENTLEY-KNIGHT CONDUIT AS LAID IN BOSTON

At the Chicago Exposition there was also another experimental electric railway built by Chas. Van Depoele. In this line the car was suspended from the rails and ran around the exposition building. In 1885 Mr. Van Depoele put in operation at the Toronto Exposition Toronto, Canada, an electric trolley railway, which it has been claimed was the first commercial trolley car line ever put in operation. This was not strictly a street railway line, but ran from the terminus of the city street railway to the Exposition grounds, something over half a mile, and was operated only during the Exposition. A motor car and three trailers constituted the equipment. On this line a speed of thirty miles per hour was attained, and an average of 10,000 passengers per day were carried. The track rails were used for the return circuit, and on top of the car was placed one of the first illustrations of the under running trolley now so universally employed.

Mr. Van Depoele's next venture was the construction of a regular street railway in South Bend, Indiana. On this line were operated as many at five separate cars, something never before attempted or even supposed possible. This road derived its current from a generating plant driven by water power. There were four ordinary closed cars equipped with one 5 H. P. motor each and one large car equipped with a 10 H. P. motor. On the cars the motors were placed under the car body between the wheels, and the axles were connected by means of sprocket wheels and link belts. This arrangement of putting the motor below the floor of the cars, was found to be advantageous, as the earlier arrangement of placing the motor on the floor of the cars took up much valuable space which could be used for passengers. On this road an innovation was introduced in the use of the over-running trolley instead of the under-running style, as was used at Toronto. The cars on this line were not reversible, but always run the same end forward. The first use of the carbon brush motor is also attributed to Mr. Van Depoele and was put into operation on the line.

Prior to the introduction of the carbon brush on railway motors, the brushes used were similar to the then prevalent type of dynamo brushes made of thin strips of copper. These brushes were a never ending source of trouble in railway work, due not only to their inherent unreliability under the rough use on a railway motor, but due also to the trouble from dirt and moisture which was encountered along the unimproved streets. These early motors were of the open type and offered little protection from dust and weather.

Some of the early types of motors were fitted with two commutators and two sets of brushes, one on either end of the armature, and is was no uncommon thing for the motorman to stop two or three times per trip and put in new brushes.



An Early Electric Car with Motor on Front Platform.

The rheostat or resistance for regulating the speed was also a complicated and annoying piece of apparatus. It was at first placed beneath the car and manipulated by a coffee mill style of controller, which the motorman ground around two or three times to throw on the power. Afterward this rheostat was placed upon the platform, but was always a menace to life and limb.

These things seem amusing now as we examine them in a reminiscent way, but they were most exasperating at the time, for an exhibition of trouble on a street railway car, partook of so much publicity from the very nature of things, that every little trouble seemed to be magnified, and it was hard to convince the public that such troubles were only transitory, and that their discovery meant their elimination. It required just such enthusiastic experiments as the South Bend road to show up the weak spots and pave the way for better things.

Following the construction of the South Bend road, Mr. Van Depoele built a large number of lines, under his system, during the next few years, some of which continued in operation and some of which fell by the wayside. One in particular, which was constructed in Windsor, Canada, in 1886, was remarkable to the writer as constituting the first electric railway which he had ever seen. He visited Windsor and examined the railway with a great deal of interest. At the time of this visit the road was in a state of inocuous destuetude and apparently had been in that state for some time. The one car, the total equipment of the road, stood at the end of the line, where it had apparently stood motionless for many moons. The trolley was a miniature car which was drawn along the trolley wire by a flexible conductor.

The Van Depoele Co. was absorbed by the Thompson-Houston Co., in 1888 and Mr. Van Depoele became an engineer for that company. The following year the Thompson-Houston Co. took over the Brush Co., which also brought the Bentley-Knight Co., into the consolidation.

At about this same time Mr. John C. Henry, of Kansas City, was working on an electric railway system of his own invention, which attracted considerable attention. He put in operation several experimental lines, using the Van Depoele motor and the trolley collector with overhead wires. In the fall of 1885 he conducted a series of experiments with heavy electric equipment, on a branch of the Fort Scott Steam Railway, where freight cars were hauled by electric motors. He also attempted high speeds and operated over heavy grades under all sorts of varying conditions to demonstrate the practicability of equipment. These experiments were carried on during severe winter weather, to demonstrate the effect of deep snows. The following year he equipped the Kansas City Fifth Street Railway with his system. In 1887 Mr. Henry moved to San Diego, California, where he built a number of lines, one of which had grades of 9%. The system of underground feeders was first introduced on one of these roads.

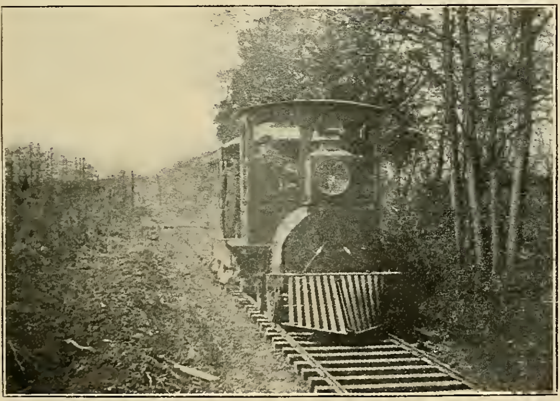
Coincident with Mr. Henry's work in Kansas City, some interesting work was being carried on in Denver by Professor Sidney H. Short, of the University of Denver, upon an experimental electric railway 300 or 400 feet long upon the college campus. Professor Short believed in the series system of distribution and used this system on his lines. The cars used on the campus line had a rigid four wheel truck, and the motors were geared with one pinion and gear to the axle. The car body was eight feet long. The success of this line was so great that a party of capitalists induced Mr. Short to give up his professorship and develop a commercial electric street railway. The conduit system was adopted and five miles of track were laid on 15th St., Denver, and operated with considerable success for some time. The difficulty of insulation in the conduit in wet and snowy weather and the imperfection of the early types of motors and generators led to electricity being finally abandoned for the cable, which, however, has since been changed back to electricity.

Mr. Short afterward went to Columbus, Ohio, and later to Cleveland, where in 1889 he organized the Short Electric Railway Co. This was merged into the Walker Electric Co. shortly afterward, and the Walker Company was finally taken over by the Westinghouse Electric and Manufacturing Co.

It is thus seen that the early eighties were active years in competitive demonstrations of electric railways, but all of these enterprises were more or less experimental, and all of the equipment used prior to 1887, was destined to be superseded by more economical and efficient apparatus.

With the year 1887 began the actual construction of actual roads, for with that year the vast numbers of previous experiments began to bear fruit in the way of practical results.

On December 31st of that year there were twelve successful electric railways being operated in the United States and Canada with an aggregate mileage of less than fifty miles of track. The electrical equipment of these twelve roads consisted of fifty or sixty motor cars. Of these roads, six were on the Van Depoele system, three on the Daft system, and one each on the Fisher, Short and Henry systems.



The Edison Electric Passenger Locomotive of 1882.

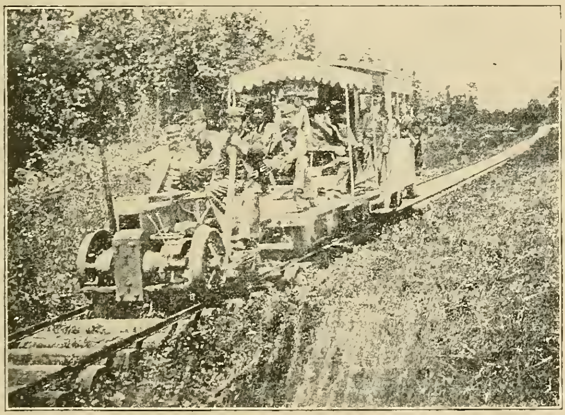
This was the situation when Mr. Frank Sprague entered the electric street railway field. There was no standard of construction either in size of cars, style of equipment, gage of track, kind of rail or method of power transmission. Mr. Sprague had been working for a number of years upon the perfection of his motor and had established himself in the field of stationary electric motors before attempting to use his motors for railway service. And his first active work in this line was begun in 1887. Prior to this he had done considerable experimental work with his motor in New York upon a private track and upon the 34th Street branch of the elevated railway.

In the spring of 1887 the Sprague Electric Railway and Motor Co. received contracts for roads in St. Joseph, Mo., and Richmond, Va. The Richmond road is generally referred to as the first successful electric railway ever constructed and while this does not imply that the roads of Van Depoele, Daft and others would not have been successful when the obstacles were overcome, and in fact were improved afterward until they were successful, it still remains a fact that the Richmond road was the first to work out of the preliminary difficulties and attract attention as a thoroughly successful commercial enterprises, worthy of copying.

After twenty years of development we would now look upon the construction and equipment of the Richmond road as a boy's size affair, but at that time it was the biggest thing of the kind ever attempted. The road was a new one, as distinguished from the changing over of horse car lines, and included a complete generating station, erection of overhead lines, and equipment of forty cars with two 7½ h. p. motors each, on plans largely new and untried. The contract required that it must be possible to operate thirty of these cars at one time. The conditions in Richmond made the requirements for grades and alignment very severe, and the road as built had 29 curves, some of them of less than 30 feet radius and grades reaching 10%. The contract required the completion of the entire track ready for operation in 90 days. The track was laid with 27 lb. rails. The overhead construction consisted of a small trolley wire reinforced with a continuous main conductor placed over the center of the track and supplied with current by feeder circuits from the main power station. The track constituted the return circuit, the rails being bonded together and connected with a continuous conductor, which was also connected with the ground plates and with the water and gas mains of the city. The power house was equipped with small belted units and generated constant potential current at about 450 volts. The cars were 16 feet in length, and as said, were equipped with two 7½ h. p. motors. These motors although built according to the best known design at that time, constructed in one of the best equipped electric manufacturing shops of the country, were so poorly adapted to the service that was required of them that every one of them required the rewinding of its field coils and armature and the changing of its commutators. The principal characteristics of Sprague's motor-equipment as used on the Richmond road, which contributed largely to its success and was an improvement over earlier systems were, an independent truck with motors exteriorly centered upon the driven axle so as to maintain parallelism between the driving shaft and the driven axles. flexible supports for part of the weights of the motors on the trucks to allow perfect freedom in following the motion of the axles, suspension being below the car springs. The method of flexible suspension avoided all shock and jar. He also used fixed brushes, allowing forward and backward running. This equipment marked the abolishing of ropes, belts, sprocket wheels and chains for the reduction between armature and axle.

In spite of many difficulties and a host of obstacles which had to be overcome, the Richmond road was a success and continued in operation until it was later absorbed by a more modern system. This road attracted wide attention in street railway and financial circles.

The Sprague Electric Railway and Motor Co. depended largely on the Edison General Electric Co. for the manufacture of motors, and in this way the Edison Co. became interested in the electric railway field. The Edison Co. advanced money to Sprague to carry on his business, a consequence of which was that the Sprague Electric Railway and Motor Co. was soon absorbed by the Edison Co., all of which were later merged into the General Electric Co.



The first Edison Electric Locomotive and train, 1880.

After the year 1888, the electric railway business of the United States was established on a firm basis. The large electric manufacturing companies which had already developed an extensive business in the electric lighting field, became interested in the manufacture of electric railway equipment. The Thompson-Houston Co. was one of the pioneers in railway motor construction. The first step in this direction was the purchase by it of the patents of Bentley and Knight and those of Van Depoele. Shortly afterward the Thompson-Houston Co. took over the Brush Co. and began on a large scale the construction of railway motors. The services of Mr. Van Depoele were also secured in the designing department of this company. The first motors turned out by the Thompson-Houston Co. were what were known as the F-30 motor. This was a 15 h. p. motor, and two were used to the car. Four thousand six hundred of these were sold by this company during the years 1888-91. These are said to be the first motors on which the carbon brush was used. Without the carbon brush the railway motor could never have attained the success it has.

In 1890 the Edison General Co. took over the Sprague Co. and actively entered into the manufacture of railway equipment. Shortly after this, several of the men who had been active in the Sprague Co., and who owing to the consolidation of the Sprague and Edison companies, were left on the outside, induced the Westinghouse Co. to take up the manufacture of railway motors.

Thus with the year 1891 there were three large companies actively competing for this class of business. In 1892 the Edison General and the Thompson-Houston companies were merged into the General Electric Co. Since that time this company and the Westinghouse Co. have been the two principal factors in electric railway manufacture. The Westinghouse Co. in 1898 took over the Walker Co., of Cleveland, who had eight or nine years previously secured the services of Professor Short as Chief Engineer.

During the six years from 1888, the time when the success of the street railway was assured, to 1894, when the street railway began to expand into the interurban railway, the growth of the electric street railway was very rapid. During these six years the electric railways of the United States increased from less than 300 miles in 1888 to over 10,000 miles in 1894.

It must be remarked, however, that this does not represent new enterprises altogether, for it was during this time that a great majority of the horse car lines and steam dummy lines were changed over to electricty. It is shown that in 1888 there were 289 miles of electric railways and 6,800 miles of street railways propelled by other means; in 1892 the electric railways exceeded the combined mileage of all other kinds of street railways, there being 5,934 miles of electric against 5,695 miles of all other kinds, while in 1894 the electric railway had to its credit 13,598 miles of line, against 3,225 miles of all other kinds. This information should be considered in connection with the fact that cable railways continued to increase up until 1894.

The most interesting problems in electric railway construction after 1894 were in the development of the interurban lines and the electrification of the elevated roads in New York and Chicago.

The elevated railway had proved its usefulness in several of the larger cities prior to 1894 but cars on these had all been propelled by steam power. These steam roads were successfully operated in the east for a number of years and seemed to give good satisfaction, RAILWAY STATISTICS.

United States.			Foreign Countries.		
Years	Steam Rys. mis.	Electric Rys. mis.	Country	Steam Rys. mis. '08	Elec.Rys. mis.'00
1880	93,262	-------	Germany	30,777	3,000
1885	128,320	-------	Austria	21,805	630
1886	136,338	8	Gt.Brit.	21,529	2,400
1887	149,214	29	France	25,898	1,200
1888	156,114	289	Russia	26,414	
1889	161,276	805	Italy	9,759	105
1890	166,654	1,262	Belgium	3,781	35
1895	181,065	12,133	Neth'lds	1,965	983
1900	194,262	19,314	Switz'ld	2,302	109
1905	217,341	33,100	Spain	8,103	349
1906	222,200	35,000	Sweden	6,359	

and were profitable. But in Chicago the conditions proved different, either because their installation in Chicago came at a time when the people had become educated to something better, or because the people of Chicago would not be contented with a class of transportation which was considered adequate by the people of Boston and New York. At any rate the elevated roads which were started in Chicago with steam locomotives did not prosper, and it was not until electricity had been substituted for steam that these roads proved successful either from a financial or popular standpoint.

The intramural railway at the Chicago World's Fair was the first electric elevated railway put into operation in the United States, and its very successful operation proved the practicability and reliability of electricity as a motive power for elevated railways, demonstrating the correctness of the contention made by Daft, Field, Sprague and others who had carried on their experiments on the New York elevated roads, that electricity was superior to steam for that purpose. The third rail method of current distribution was also thoroughly demonstrated on the intramural road, and there was no further doubt of the thorough reliability of electric elevated railways for heavy traffic and frequent stops.

The Metropolitan Elevated Railway, in Chicago, was already projected at the time of the World's Fair and was designed for the use of steam locomotives. The Lake Street Elevated and the South Side Elevated were already in operation with steam locomotives. After the success of the intramural railway the Metropolitan Railway cancelled the orders for steam locomotives and decided to adopt electric motors. The plan adopted, was for a large electric motor car which acted in the place of the steam locomotive and hauled the train, all of which was composed of trailers. This was the first regular city electric elevated railway ever put into operation.

Largely as the result of the success of the intramural railway the Northwestern Elevated was projected in 1893, and the franchise was obtained with the express understanding that the road would be operated electrically. This was the first electric elevated railway ever designed, as such, in the United States. This was also the first four track elevated road in Chicago, if not in the United States.

Not long after the World's Fair the South Side Elevated Railway decided to change its motive power from steam to electricity At first thought this no doubt seemed a comparatively simple problem but a little investigation unearthed some very obstinate difficulties which seemed almost unsurmountable, if a single electric locomotive were to be used to haul a train of three or four cars. The need of long trains on this line was already obvious, but the structure was not heavy enough to safely carry such heavy motor cars as would be required to draw these trains. Mr. Frank Sprague, of New York, was invited by the engineers of the South Side Co. to invesigate the problem and submit a plan for the electrification. He very strongly recommended a system which he had invented a short time before, of multiple unit control, by which every car in the train could be a motor car if desirable and all could be operated by a master controller located at the head of the train. This system had not been put into practical operation prior to its use on the South Side road, and there was considerable speculation as to its practicability. But after the first few trials which developed some rather serious miscalculations, the system worked splendidly. The system of multiple unit control has been very generally adopted in all electric train operation since its installation on the South Side Elevated. A short time after the Chicago Elevated roads had changed to electricity, the New York Elevated followed.

Another interesting electrification problem which was carried out at the same time that the first elevated roads were changing to electricity, was the adoption of electric locomotives for hauling the steam trains through the Belt Line tunnel of the Baltimore & Ohio Railroad in Baltimore. The first of these locomotives was put in service in 1895. The use of steam locomotives in long tunnels had always been known to be a dangerous practice, owing to the deadly gases from the burning coal. There had already been a number of bad accidents in tunnels in which a number of lives were lost and the need for a safe substitute for the steam locomotive had been very urgent for a long time. So the use of an electric locomotive for this purpose was felt to be very desirable, and this effort to use an electric locomotive in the Baltimore tunnel was watched with great interest. The success of this venture into an unknown field, was assured almost from the start, and the electrification of other tunnels have followed. It goes without saying that all the newer tunnels now being constructed beneath the rivers in New York, Detroit and elsewhere for steam railways, will be operated electrically, and further than this, in many of the mountain tunnels of the west there is now under consideration the electrification of certain systems of road involving these tunnels. Another circumstance that makes this class of electrification desirable is that electric locomotives are much more efficient than steam locomotives on heavy grade, and heavy grades and mountain tunnels are generally found in close proximity.

The first interurban railway to be put in operation seems to have been out of Cleveland, although it is hard to distinguish between the urban and the interurban in many cases where the street car lines were extended further and further out of the cities along the country roads until they finally connected one city with other towns and cities and thus become interurban.

One of the earliest premeditated lines to be constructed was the Akron, Bedford and Cleveland. This road is 35 miles long and was first planned in 1892 and 1893, and was put in operation in 1894. At that time the direct current transmission at a low voltage was the best known method of distributing current to the cars, and a line 35 miles long was a gigantic enterprise. In 1894 not only was high tension transmission unheard of for electric railways, but the art of high tension transmission for any purpose was only in its infancy. It will be remembered that it was not until the following year that the Niagara Falls transmission line was put into operation, and this has been considered the pioneer high tension transmission line in this country, although there were some lines on the Pacific Coast constructed about this time.

The real growth of the long modern interurban railway began with the introduction of the rotary converter and high tension alternating current transmission into railway work. The first practical proposal for a line designed to use high tension alternating current and rotary converter sub-stations seems to have been in 1896, by B. J. Arnold, in plans for a road to run between Chicago and the Wisconsin Lake region. There was a rotary converter used prior to this in connection with a railway in Concord, New Hampshire, where the power was derived from a water power plant, but this was at that time looked upon rather as a makeshift. Mr. Arnold's road to the lake region was never built, but the plans were utilized two years later upon another line which was operated very successfully from the start.

The central power station had been developed in the meantime with the introduction of large direct connected units, replacing the small belted units previously employed. The efficacy of this method of power generation had been proved at the Chicago Worlds Fair in connection with the intramural railway. The large central power station seems now an indespensible adjunct to all modern interurban lines and is being substituted for the small isolated plant for every kind of electric railway. The intramural power plant was for D. C. current entirely, as in fact were all railway power plants prior to 1896, but the principles demonstrated applied equally well to either D. C. or A. C. distribution.

As soon as the fact was fully demonstrated, that long electric lines were entirely feasible with A. C. distribution of power, the art of electric railroading had established itself on a permanent basis. And as fast service was established, the steam roads' standard of construction was adopted. On the best lines that have been constructed in the last five or six years, the grades and curves have been made very gradual and the rolling stock has been made capable of high speeds. The fact has now been demonstrated beyond dispute that as high speed can be attained by electric trains as by steam trains, and there seems to be no question but that the ease and safety will be favorable to the electric line.

The running of the long electric lines immediately parallel and adjacent to the competing steam lines has appeared to the layman an inexplicable riddle, but the reasons for this apparent phenomenon are sound business reasons.

The writer predicts that in the future the electric roads will push more and more out into the undeveloped country, especially where water power is available, and as the freight and express business become more important factors.

The electrification of steam lines is becoming an accomplished fact, as illustrated by the New York Central R. R. in New York, and the other changes of less magnitude in the East. How rapidly this change from steam to electric propulsion of trains will be carried out on the trunk lines is hard to predict, but that the change will be made seems to the writer a foregone conclusion. The high speed electric railway is with us to stay. How great the change it will bring about in the civilization of this country is not possible to predict.

DISCUSSION.

Mr. W. D. Roper, (Chairman): The development of the electric railway has been one of the marvels of the age; the entire development having taken place within the memory of nearly all of us; it is something we have all been able to watch and note the progress. In looking forward to new developments in any line, it is expedient to occasionally pause in our forward progress and note the lines in which the development has taken place,—as a surveyor would put it, in order to be sure your forward progress is on proper lines, you want to make sure of your back sight.

Mr. Hatch has gone very thoroughly over the development of the electric railway system—its evolution from the early beginnings. A great many of the early attempts have been noted and watched by many of us, and some of the illustrations which appeared on the screen are similar to some of the scenes here in Chicago.

The remarkable development of the electric railway system may perhaps be compared to the growth of the lighting systems in the country. The lighting and power business has, as you all know, undergone a very remarkable and rapid growth, especially in the larger cities. In making a study of the electrical development and prospective development in one of the large cities some years ago, I found that the power used by the electric railway systems in a number of the large cities averaged about three times the amount of power supplied by the public service corporations in the lighting and power business, and that ratio is approximately true at the present time, not only in Chicago but other large cities; that is, the total electric railway power is about three times the total of the commercial lighting and power business. This may give one some idea as to the magnitude of the railway business as compared with the lighting business, especially as we add to that, the amount of power used in connection with the very numerous interurban systems.

The traction systems in Chicago, as you all know, have been very materially influenced in the past few years by the franchise question. That situation has developed rather an unusual condition, especially as to the improvements, growth, and extension in the past few years. The traction companies all being forced by public sentiment to improve their service, yet in a position where it was difficult to secure additional funds for extension of their plants, and further, in their negotiations with the city they were given but a limited time in which they guaranteed certain improvements. As it was very difficult to install additional generating machinery in that period, as well as difficult to secure the required capital, the traction managers found that they could secure power for their purpose in the required time from the Commonwealth Edison Co. In fact they were able to secure power in this manner by means of underground cables from the generating stations of the lighting company as fast as they could secure rotary converters and cars. The result of this situation is that the local lighting company, for several years past, has secured all the increase in the load that has taken place in all of the surface lines and several of the elevated lines. At the present time about half of the output of the local company is used for railway purposes.

Mr. Lincoln Nissley: When I came here this evening I did not expect to enter into the discussion of the paper, not being a member of this Society, but the excellent treatment of the subject by the author of the paper, and the attractive views shown, has brought my reminiscent mood into play.

The very early demonstrations that we have had, in this country especially, have been very clearly outlined in Mr. Hatch's paper. In looking back over the past, it seems to me there were a great many more engineering difficulties than at the present time. Financially, the early pioneers in the Electric Railway field were handicapped also, owing to the fact that very few capitalists would advance the money for a liberal exploiting of the systems, and they were simply groping along the best way they could. For instance, the Sprague motors were made, not in one shop but certain parts were made in one place, other parts in another, and they were finally assembled and shipped to Richmond and other places, and placed under old horse cars, totally unfit for the purpose when compared with rolling stock of today.

I remember visiting the Richmond road, and in riding out over the road, I noticed that the joints on the track were bent and hammered down probably half an inch, and an inch in some cases, on account of poor track construction. Many of you will doubtless remember that it was thought at that time that bonding was not necessary, and the first bonds used were galvanized iron bonds. fastened to the rails with drift pins.

The early roads of Daft were equipped with cars of the locomotive type, hauling trailers. I can remember distinctly of seeing one of those types fixed up as one of the big show pieces, when it was considered as the most modern car.

An early type of car consisted of the Westinghouse gearless motor (thirty-two of which were in operation at that time), and also the Short gearless motor, but that type of motor gradually dropped out of use. But now, in our heavy locomotive work, we are getting back to the gearless motor once more.

I do not wish to disagree with anything Mr. Hatch has said in his paper, but I think credit has been given to some people where it does not belong. For instance, Mr. J. C. Henry was a very early pioneer in electric railway work. In 1888 he invented a regenerating controller. His idea was that when the car was going down the grades, the motors would generate power proportioned to its speed and deliver it back to the line, but he never succeeded in making a success of the regenerating controller.

The early motors of Sprague, Daft, Henry, Van Depoele, Bentley, Knight and others were of the double reduction type. Of course we who have seen the operation of those open motors, know that they were not waterproof, and they soon deteriorated, and on account of the great cost in keeping them in repairs, etc., they were soon replaced by the enclosed type, or waterproof motor. The first waterproof motor made in this country was manufactured by the Thomson-Houston Co. before its consolidation with the Edison Co. I have seen, personally, some of these motors operating in the street where there were two or three feet of water, and they operated without being burned out, which was thought at that time a great advance in the art.

The evolution, advancement and remarkable progress made in the electric railway field is beyond any engineering progress in this country. Today our motors are not only much higher in efficiency, but will operate from two to three months without any care whatever, and that is quite an item when it comes to winding up the year's affairs and getting up the profit and loss account.

Again, in speaking of the electrical railway development, Mr. Hatch is correct in saying that the Akron, Bedford and Cleveland line was the first interurban railway in this country. I might say that a double current generator was manufactured by the Westinghouse Co. for this road for the purpose of transmitting direct current from one side of the machine out a certain distance, on the line, and then from the other side of the commutating part of the armature taking alternating current and transmitting at a great distance or beyond the economic distance alowable for 600 volts direct current.

One of the largest single phase installations, is the Indianapolis and Cincinnati railway. The company has 147 miles of road, and they operate at very high speed, 50 ton cars, and very successfully, too. Personally, I consider that that is the first successful single phase electric railway in this country for long distance interurban work. Of course the New York, New Haven and Hartford single phase electrification is on a much larger scale. The great controversy that was at one time going on between the advocates of the overhead trolley and the third rail system has disappeared entirely from the arena. Daft's old Mt. McGregor road has been again brought to the front in its type of construction; the Hudson and Albany line being a similar installation, so far as the third rail goes.

The patent controversy was a great hindrance in the early introduction of the electric railway, and the large electric companies spent several million dollars annually to protect patents. This difficutty, fortunately, has all disappeared from the field.

As to the results of our interurban railroads, I would like to say this,—that so far as opening up communication between the larger and smaller centers of population is concerned, they have been a great success. From a financial standpoint, however, some of them have been failures, for out of the fifty-seven railways in Ohio only eight paid dividends last year. The question must arise,—are we going to develop further the interurban railroad in the United States? We certainly will continue, but there must be some returns for the capital invested; the railroads must earn some money on their initial cost. If you are at all familiar with statistics of the roads in the middle west, you may remember that the electric railway costs, per mile of road bed, from $20,000 to $30,000; so the earning capacity must be somewhere from $3,000 to $4,500 per mile of road bed to pay interest on the investment. By observing the statistics of the census reports, one will find the cost running up from $50,000 to $65,000 per mile of road bed, and that the earning power is only about $2,000 to $5,000 per mile, yet companies are continuing to go on and do what no other railroad has ever done in a certain respect. They have done what, in my judgment, the steam railroad never did in its early days,—carry a passenger for so small a fare,—deliver him speedily, safely and every hour of the day at his destination. As has been remarked here this evening, the electric railway is one of the marvels of the age; let me add that it is here to stay no doubt, and will continue to develop as a potent factor in the vast transportation systems which are yet to be on this continent.

Mr. W. E. Symons, M.W.S.E.: I have been much interested in this paper although not an authority on the evolution or development of electric railways, or electricity as a means of propulsion.

Mr. Hatch's paper has made both of these matters very clear, particularly the conception and early development of electric propulsion, and this information so ably prepared and presented will become more valuable to this Society and to the engineering world, as time goes on, and the records from which such information must be secured become more obscure. This very able review, together with Mr. Nissley's remarks, has prompted me to ask some questions of the author, or possibly Mr. Nissley may feel disposed to answer some of them.

All of us who have observed the development of anything of a scientific or mechanical nature can recall, that the early efforts have usually met with very slight encouragement, and not infrequently open ridicule, or hostility; all of which added to the disadvantages to be overcome. This has been especially marked with reference to all great factors in our modern civilization. Taking, for instance, the first efforts to develop the steam boat: John Fitch, who was one of the first and most worthy of recognition, was looked upon by some as of unsound mind. After he had built his second boat, and with much effort had induced some friends, whom he hoped to interest both in a scientific and financial way, to inspect the craft, he said to them "Gentlemen, it may be after my time, but this will eventually be the means of carrying both freight and passengers not only in our coastwise trade and rivers, but across the ocean." As the friends turned to walk away, one said to the other "What a pity the poor fellow is crazy." Similar treatment was accorded the early inventors of steam locomotives; it was the same with the telephone and electric propulsion.

It is not a long time since a very bitter controversy was going on between the two principal leaders in the electric development of this country, as to the relative advantages of their respective systems of electric propulsion.

The patents under which these two systems were manufactured having been pooled I think it would be interesting to know if any conclusion has been reached between, or by, these former contending companies, or the users of either systems as to which is the most desirable, practicable and economical, and what, if any, objectionable features formerly so strongly emphasized by each company with reference to the other's system has in any measures been eliminated, or improved upon.

Some two years ago the country was startled by the announcement in the public press of a terrible railway accident, wherein passengers were killed; some having suffered death by fire. The newspapers commented much on this, and pointed out that if electricity were used as a means of propulsion, danger to passengers and property from fire was impossible. A few days following this, however, a very bad accident occurred on one of the prominent railways running out of New York City, which had been recently electrified; the results in the latter case were almost as disastrous, both to property, life and limb as in the former. In fact, if the newspaper accounts were correct, some of the passengers suffered death from burning, which would indicate that even on electric trains passengers are not entirely free from the danger of fire.

In the matter of relative cost of steam and electric railways, while this does not come within the scope of the speaker's paper, it would be very interesting to know his views as to the relative cost of a horse power delivered at the draw-bar of an electric locomotive as compared to that of a steam locomotive.

In the matter of electrification of steam railway terminals referred to by Mr. Nissley, will say, there are a number of intricate problems in connection with work of this kind, which yet remain unsolved; this is particularly true with respect to the question of providing adequate switching facilities. Main line trains are very easily and successfully handled, but the question of switching in the yards where trains are assembled for departure, and in handling industry track work, is very complex, and if the author of the paper, or Mr. Nissley, could offer some suggestions in connection with this feature of electrification, it would be very interesting.

Also if any data has been compiled as to the schedule of electric equipment to date, showing the number of electric locomotives in service in America at the present time.

Mr. Roper: Two of the speakers this evening have referred to the patent situation. During the last ten or fifteen years this has been an important feature in electrical developments. About twelve years ago I was connected with one of the large manufacturing companies—the time when the patent situation was at its worst. At that time one of the largest manufacturing companies controlled the patents on the controller and the trolley. Another company controlled the polyphase transmission patents, as well as the fundamental patents on transformers. These were the principal patents, and each company was very industrially engaged in collecting testimony and evidence of various kinds which would render void the patents of the other company. Personally, I was engaged in making experiments on some machines which had been brought over from Paris, which had been in use some ten or fifteen years before that time, and which combined all the elements of the modern polyphase alternator. These machines were built by Mr. Gramme and were two-phase revolving field machines with removable pole pieces. We succeeded in running one as a two-phase generator and one as a self-starting two-phase motor. The indications at that time were that each company would be successful in producing information that would nullify the patents of the other. About this time it developed that if each succeeded in doing this it would immediately open up the entire field to all competitors, and so, rather than do this, they apparently agreed that it would be a better commercial solution of the problem to pool the patents than to nullify all their patents and thereby open up the entire field. Shortly afterward, the experiments were discontinued, and the matter quieted down, and not many months afterwards the patent agreement appeared.

Mr. Hatch: I am not prepared at this time to answer the questions which Mr. Symons has asked.

Mr. Nissley: The reference I made to patents was simply to bring out the point that we had great success after pooling the patents, and I think the Chairman has voiced my sentiments and answered that question. While I might have been a little perverse at that time in making that statement, it has had nevertheless great influence in forwarding the electrical industry.

Mr. Geo. M. Mayer, M.W.S.E.: Referring to some details which the speaker of the evening brought up—the brush troubles more in particular. The motor was not perfected at that time, and a good deal of sparking from the metal brushes was met with, hence the commutator of the dynamos or motors had to be turned down frequently. This trouble was avoided through the introduction of the carbon brush. The electric cars were merely remodeled horse cars, and followed no particular design in conformance with the general equipment. This matter, as we know, was adjusted later on.

Mr. Roper: The tractive effort of a steam or electric locomotive is largely a matter of weight. The electric locomotive, with the same weight, can probably produce a little larger tractive effort, because it has a more uniform pull than a steam locomotive.

There have been a number of amusing instances along that line, one of which I learned recently from one of the engineers of the New York Central Railroad: One of their steam locomotives used for drawing tarins, in going through the tunnel near the Grand Central Station, stopped and was unable to start up the grade. Shortly afterward, another train came along, and the second locomotive was unable to push the first one out. This trouble was probably aggravated by the gas and fumes in the tunnel, but the fact remains that, shortly after this a third train came along with an electric locomotive, and succeeded in pushing the two trains out. This incident created considerable comment at the time, and the steam locomotive engineers could not understand how the electric locomotive was able to develop sufficient power for the purpose. Local conditions were probably a large factor in the case, and the electric locomotive was not at all bothered by the fumes and gases in the tunnel. Also, the electric motor, as we all know, has the power of developing considerable overloads for a short period without any difficulty whatever.

Mr. Symons: It is barely possible that my question with reference to the relative cost of steam and electric horse power was not made perfectly clear. What I wish to get at is the cost of producing a horsepower at the draw bar of any particular unit that might be considered. To make the matter more clear, we will consider the steam locomotive; among the most efficient engines that were tested on the testing plant at the St. Louis Exposition one of these delivered a horsepower at the draw bar with a consumption of 2½ lbs. of coal per hour. In actual service on the road in handling trains, however, the amount of coal would be very much in excess of this, possibly more than double; this for various reasons; the conditions are less favorable on roads in every way, the engines being outdoors, there is greater loss of heat. Again, the quality of coal furnished for use in laboratory work is invariably good, while that furnished on the road is universally of a more inferior quality. Therefore, the number of pounds of coal consumed per horsepower would probably run about 5 under the most favorable conditions, and frequently to 8 or 10 lbs. where the coal was bad, and it was the relative quantity of fuel consumed necessary to produce a horsepower at the draw bar between the electric and steam locomotive, which I had in view.

The pulling capacity of any locomotive, as the Chairman has well said, is governed largely by its weight, as the weight bears a direct relation to the ratio of adhesion, which in steam locomotives for freight service is usually about 1 to 4½ or 5, while with passenger locomotives it is usually about 1 to 5.

The amount of tonnage, or weight of trains that a locomotive will start depends on a number of things: Principally, the tractive power of the engine; the condition of the rail has much to do with this, and in the matter of the speed of trains the size of the boiler and the relative ratio between cylinder volume, heating surface, evaporating surface and grate area are all controlling factors in the effiicency of the machine, and, therefore, governs its performance. The type of steam locomotive in most common use has a less starting efficiency than an electric locomotive of the same weight for the reason, that the torque, or turning moment of the electric locomotive is maximum and constant at all points, and at all times, while the steam locomotive referred to, has dead points, which effects its efficiency or power. This principle is very clearly shown in the improved steam locomotive of the 4 cylinder balanced type, which provides a more constant turning moment, or torque, which approaches very closely to the efficiency of an electric locomotive in the matter of starting from a period of rest. The question of efficiency to move trains of a given weight over certain distance, however, is governed entirely by the size of the boiler, and its ability to provide steam for this purpose. The limitations of a steam locomotive is, therefore, fixed and determined by the size of its boiler, while that of an electric locomotive is governed by the power plant where the electricity is generated for its propulsion.

Mr. Roper: Regarding the starting and accelerating of trains, some of you may recall the experiments carried on some years ago by the New York Central R. R. They had a track several miles in length built by the side of their main track; they had a dummy train, consisting of the standard passenger train, loaded with sand bags. After they got in full working order, one of the favorite "stunts" of those in charge of the electric train was to get at one end of their experimental track and then wait until one of the fast trains came along at full speed. The electric locomotive would start as the engine of the fast train came alongside and would then accelerate so fast that the two would be running at the same speed before the last car of the steam train got by the electric train.

Mr. Nissley: Mr. Chairman, you have expressed it very well indeed when you stated that the advantage of the electric locomotive over the steam was first the large capacity of the electric locomotive for overload, and, second, its very high acceleration.

As Mr. Symons has stated, it is not always possible to get the full benefit of the steam locomotive, owing to certain conditions, such as quality of coal, draft, temperature, conditions of track, etc. The rating of a steam locomotive is based on the maximum tractive effort which it is capable of giving, while its capacity depends on the maximum speed at which this tractive effort may be developed. The maximum rate of dong work, therefore, for which it is possible to design a steam locomotive is established by practical limitation as to steaming capacity of the boiler and width and length of fire box.

The electric locomotive on the other hand does not generate its own power, but acts nearly as a transmitting medium through which electric power delivered to the locomotive is converted into mechanical power at the driving axles. Each driving axle of an electric locomotive being equipped with a motor, the size and horsepower which is limited by the speed at which it operates, by the gage of the track, and by the diameter of the whole, it becomes only necessary to provide a sufficient number of driving axles to permit the electric locomotive to deliver the greatest tractive effort that the draw bars of a train will stand at any speed permitted by considerations of safety in operation, and reasonable cost of track maintenance.

Herein lies the chief advantage of the electric locomotive, the increase in speed of the heavy freight trains making it possible to double and in many cases triple the tonnage capacity and consequently the earning power per mile of track. For example, the most powerful steam locomotive in existence—the six-axled, twelve-wheeled, Mallet Articulated Compound, built by the American Locomotive Co., for the B. & O. R. R.—will develop its maximum effort of 71,500 lbs. working compound at a speed of less than 10 miles per hour, whereas an eight-axle electric locomotive having the same weight on drivers, and composed of two four-axle sections, coupled together, could be made to develop an equal tractive effort at a speed of 30 miles per hour.

It will be seen that such an electric locomotive could handle three times the daily tonnage of the Mallet Compound, increasing the traffic capacity of the road in the same proportion.

The paper so ably presented here this evening by the author should be of especial value to the younger members of the profession of engineering, in spreading before them the entire results of nearly twenty years of accurate information of the more or less chaotic experiments which have led up to the comparatively staple standardization of today.

It is generally difficult to see the end from the beginning, and the application of electricity to transportation is no exception. It is therefore no small satisfaction to know that the electric railway as first installed formed the basis of the world's greatest and most pregnant industry.

THE PASSING OF THE STEAM LOCOMOTIVE

By Wilson E. Symons, M.W.S.E.

Presented Feb. 19, 1908.

INTRODUCTORY.

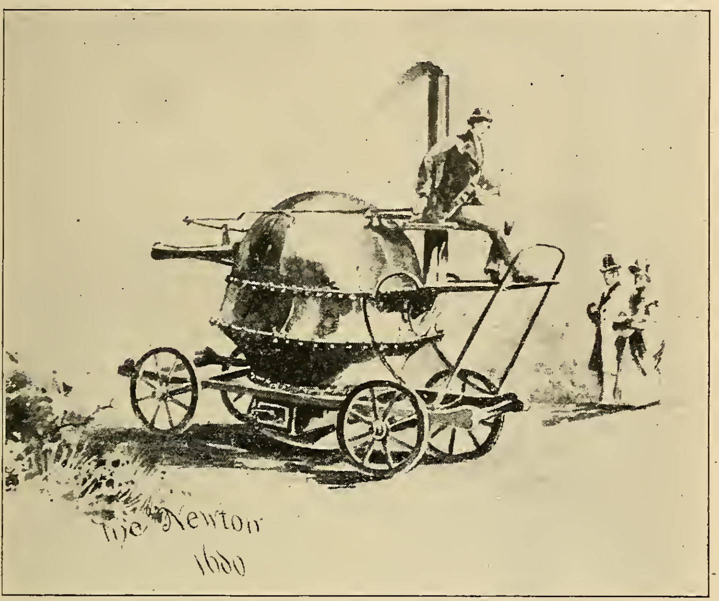
The title, under which this history of the development of the steam locomotive will be reviewed is somewhat ambiguous, if not misleading. An apology for its use lies in the fact, that a large percentage of the English speaking people, particularly residents of the United States who are in touch with, and are more or less familiar with the development of commerce, transportation and the growth of the country, have very little, if any, knowledge of the origin, growth and development of one of the greatest factors in American civilization, and many, some of whom are authority on the greatest problems of the day, actually believe that the term used, "Passing of the Steam Locomotive," is appropriately applicable in its literal sense.

It would, therefore, seem not inappropriate to review the history and development of the steam locomotive and let this review serve as an answer to such, as may be laboring under an erroneous impression, and at the same time possibly indicate in a limited degree the probable field of future activity to which this most potent factor in our commercial and financial progress will be called into requisition. To this end, and in order that the comparison may be sufficiently striking to warrant this review of its development, not only the earlier history should be considered, but the starting point should be from that earlier thought of the application of nature's forces to the uses of man; it would, therefore, seem eminently proper to refer first, to the "NEWTON" of 1680:

The "Newton" of 1680 represents the first efforts of Sir Isaac Newton in his application of steam power to move a vehicle. Newton's conception or application of this force being practically the same as Hero's, but the idea of making it serve as a means of propulsion was his own, and in the odd and curiously shaped vessel, or cauldron, which pretty much resembles a large kettle with a top fastened on so as to prevent steam escaping to the atmosphere. There was an outlet in the rear, operated by a handle from the seat in front, so as to regulate the flow of steam which reacting against the atmosphere propelled the vehicle in the opposite direction. We have here what might be termed the first step toward the modern steam locomotive, and although the device looks very odd and curious, and doubtless was looked upon as the work of a crank, yet the engineering world owes much to Sir Isaac Newton as one of its original engineers.

In 1681, 1683, 1695, 1703, 1707, 1718, 1720, 1737, 1750, 1760 and

1767, were the efforts and experiments of Papin, Moreland, Savary, Newcomen, Potter, Beighton, Neupold, Whitehaven and Murdock, the last having produced a curious looking machine in 1784, which was operated by steam through the medium of a crank axle.



The Newton Steam Locomotive.

About this time Watt appears upon the scene. His principal experiments or field of operations, had been that of pumping water out of mines. His friend, Dr. Robinson, however, had been importuning him to apply steam power to the moving of carriages, and as a result, he and his partner, Bolton, constructed a steam carriage, which they termed a "Fiery Chariot." In 1769 Watt took out a patent on his first rotary engine.

In 1786 William Symington's conception of a steam carriage on three wheels, the front wheel guiding it, was produced, in which for the first time provision was made for carrying passengers in a coach body supported and carried by three wheels.

The "Holland Sail Chariot" of 1765 and Cugnot's steam wagon used for the handling of artillery, and the Murdock's steam wagon in 1784 were fore-runners of the Symington's steam carriages of 1786.

In 1799 Oliver Evans in the United States perfected a high pressure, non-condensing steam engine, which was later applied to stationary use.

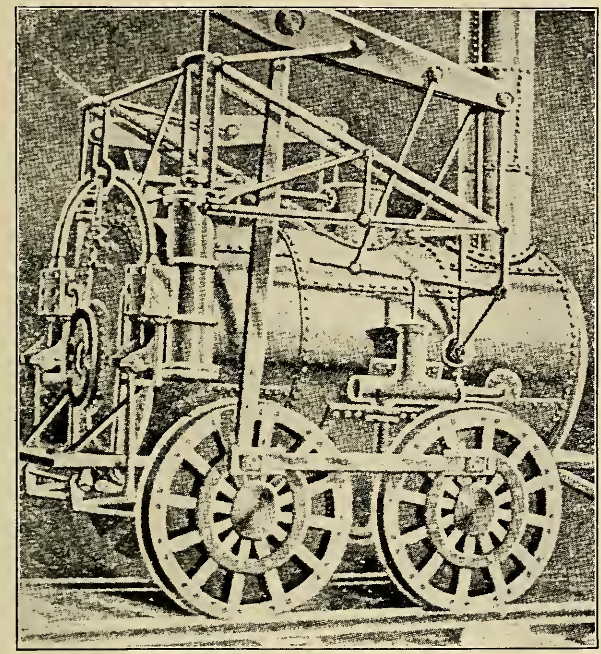
In 1800 and 1803 Richard Trevithick produced two steam propelled vehicles; the one in 1803 being a steam carriage for the conveyance of passengers. The first one was for a rack rail road, while a similar machine developed by him in 1801 was intended for highways, as was also the steam carriage of 1803. His locomotive of 1803, together with a farther development in 1805 and 1808 were intended for use on tramways. These were operated on the Merthyr Tydvil railway in South Wales, and would propel wagons containing ten tons of iron. This feat was accomplished on a bet of 50 guineas.

"The Blenkinsop" engine of 1812 was a still farther development of the rack rail device; this was introduced by Christopher Blackett on his tramway at Wylan, which had been altered to suit this type of an engine after the "Trevithick" had finally blown up, after being coaxed, bullied and prodded by the workmen. The experience with the "Blenkinsop" it is said, was almost as disastrous in results as with the "Trevithick," and although it did not blow up, it is claimed that a magnifying glass was required to detect its motion, and that more horses were required to keep it upon the track than would have been necessary to propel the load the engine was supposed to haul. The locomotive finally rolled over the embankment and thus ended its career.

Various experiments, and so called improvements, including the "Brunton" of 1813, which seemed to be on the order of a steam walking man, brings us up to the "Puffing Billy." This was the product of the brain of Mr. Hedley, a new candidate for locomotive honors, who after a successful experiment with his testing carriage, simply a frame work mounted on four wheels, in which he was the first to demonstrate in a practical way the adhesion of smooth wheels to smooth rails, proceeded to build his locomotive, the "Puffing Billy" upon the principle he had proven to be correct. The "Billy" accomplishing with comparative ease the work of ten horses. Hedley finding the weight of this locomotive on four wheels was detrimental to the track, doubled the number of wheels, and thus experimentally produced the first eight wheeler; this not proving satisfactory, however, he returned to the four-wheel style, strengthening the plates of the roadway to meet the requirements.

A number of different types were produced about this time, showing more or less the trend of thought which occupied the minds of engineers of the day. In 1816 Stephenson brought out an engine bearing his name, which was built at the West Moor shops of the Killingworth Colliery, this being his third locomotive, and one in which he introduced steam springs, an arrangement, which proved defective in principle, and was soon abandoned.

Considerable development in steam carriages for public highway use were shown in the inventions of Griffith in 1812 and of James, Burstall, Hill and Gordan in 1824. In 1825, the "Killingworth," a locomotive designed and built by Stephenson, was brought out in which he abandoned entirely the endless chain, substituting outside coupling rods, which connected the front and rear wheels. Steel springs are first introduced by Stephenson in this engine, together with an innovation in the position of cylinders, thus making the locomotive more compact, in a better form, and getting rid of numerous rods and joints.



An Early English Locomotive, the "Puffing Billy."
(From an old print.)

In 1827 the "Royal George," a four-cylinder locomotive built by the Wilsons of Newcastle, one year prior for the Stockton and Darlington road and which had not proved a success, was rebuilt and re-christened the "Royal George." This engine was so radically changed as to cause much comment, and this was practically the first introduction of the steam blast, and on a well calculated principle. The "Royal George" demonstrated a capacity far ahead of any other locomotive in England at that time.

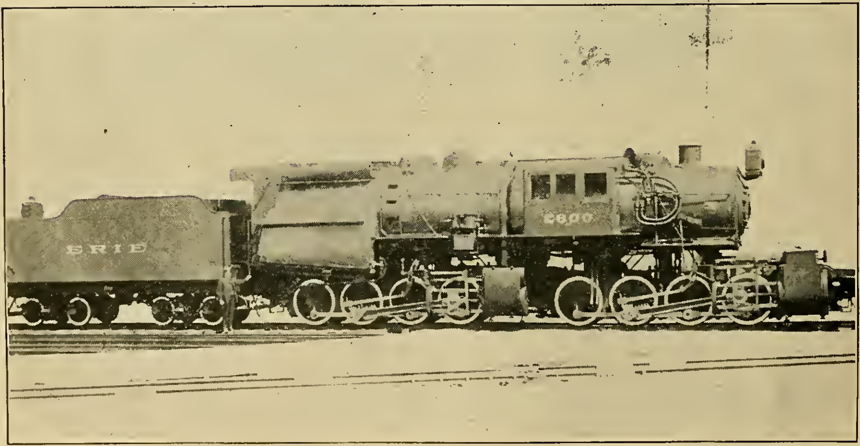
DEVELOPMENT IN AMERICA.

The review thus far, which pertains to the earlier efforts of locomotive designers abroad, brings us up to a period when the introduction of the locomotive was first considered in America, and in order that the difficulties and obstacles which were necessary to be overcome in America by the original promotors of the steam locomotive may be better appreciated, I quote from the report of a Special

Board of Commissioners appointed by the legislature of Pennsylvania in 1831, who were authorized to thoroughly investigate and report upon the practicability of the construction of railways, and the advisability of the State lending any assistance to such a project. A quotation from their report is as follows:

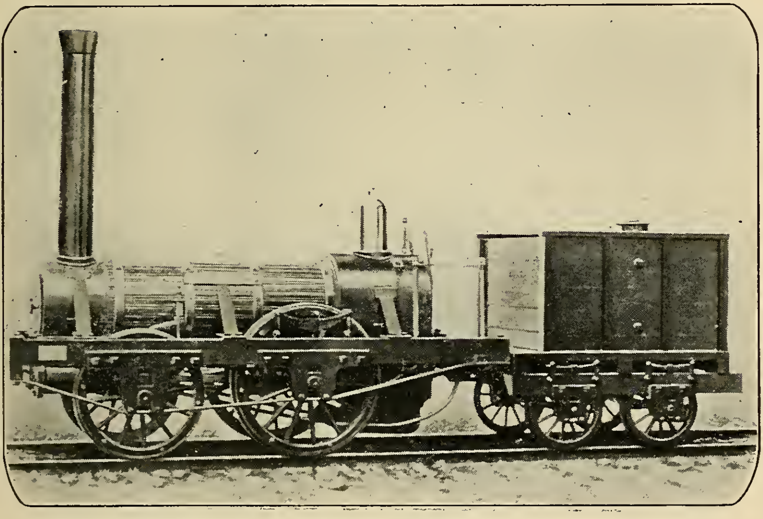
> "While the Board avow themselves favorable to railroads where it is impracticable to construct canals, or under some peculiar circumstance, they can not forbear expressing their opinion that the advocates of railroads generally have over-rated their comparative value; the Board believes that notwithstanding the improvements that have been made in railroads and locomotives it will be found that canals are from two to two and one-half times better than railroads for the purposes required of them by the State of Pennsylania, and they again repeat that their remarks flow from no hostility whatever to railways, for next to canals they are the best means that have been devised to cheapen transportation."

At the time this Report was submitted in 1831, the population of the United States (26 States) was 13,000,000, principally in eight (8) States, with an approximate area of 362,000 square miles, and an average population of twenty-four (24) per square mile. That same area now has population of ninety (90) per square mile, an increase of 275 per cent. The State of Pennsylvania was at that time the principal commonwealth, exerting a marked influence over the transportation and commercial interests of the country. The steam locomotive was at that time destined to play that important part in the development and upbuilding of the country, which a history of its progress will clearly show.



100 Ton Locomotive, Erie R. R.

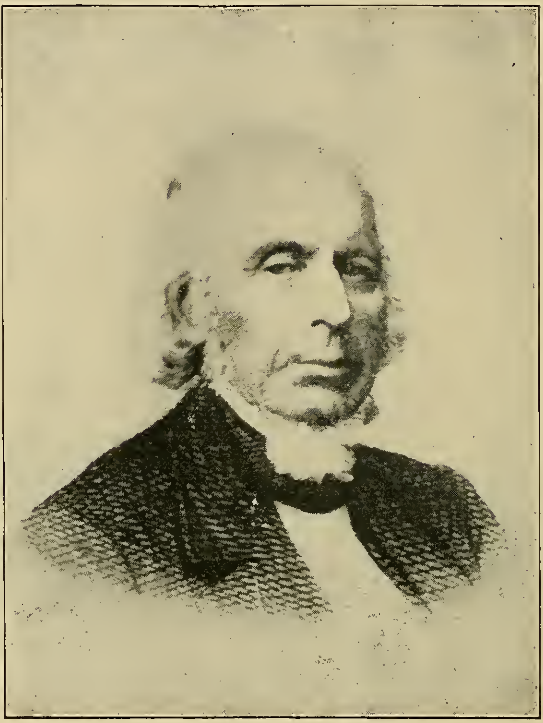
The first locomotive of which we have any authentic record in America is the Stourbridge Lion. This first steam locomotive used on the American Continent, was brought from England by the Delaware & Hudson Canal Co., and placed in service by Horatio Allen, the celebrated pioneer engineer, near Honesdale, Pa., August, 1829, on what is now a part of the Erie Railroad system. Therefore, the "Erie" holds the proud distinction of having used the first steam locomotive in America on its tracks, and also at present owning and operating the largest steam locomotive in the world, The "Stourbridge Lion" weighed 7 tons, which Mr. Allen, chief engineer, decided was too heavy for their trestles. His report closed its usefulness, it being laid away and gradually dismantled. The pieces were collected together, however, in 1905, and with some additions put together, and it is now in the Smithsonian Institute, Washington, D. C.



"Old Ironsides."

Concerning "Old Ironsides," the first locomotive built by the Baldwin Locomotive Works at Philadelphia, it would seem eminently proper to give here some facts dating from the completion of its first locomotive. The guiding spirit in this enterprise, and the one to whom credit is due for its existence and the great benefit it has been, and is today in the commercial world, was Mr. Matthias W. Baldwin, whose picture is herewith presented. Mr. Balwwin was born in Elizabeth, N. J., on December 10th, 1795, and learned the trade of a jeweler; in this connection it might be mentioned that the principal locomotive builders of the early days were jewelers or silversmiths.

In 1825 Mr. Baldwin formed a partnership with Mr. David Mason, a machinist, for manufacturing tools and cylinders for printing calicos; their business prospered, and steam power became necessary but the engine they bought for this purpose proved unsatisfactory; Mr. Baldwin designed and built an engine suitable for their requirements, and in a short time it proved so efficient that he received outside orders for additional engines. This engine, the original upright stationary, built in 1830 is still in good order, and is carefully preserved at the Baldwin Works, in Philadelphia.



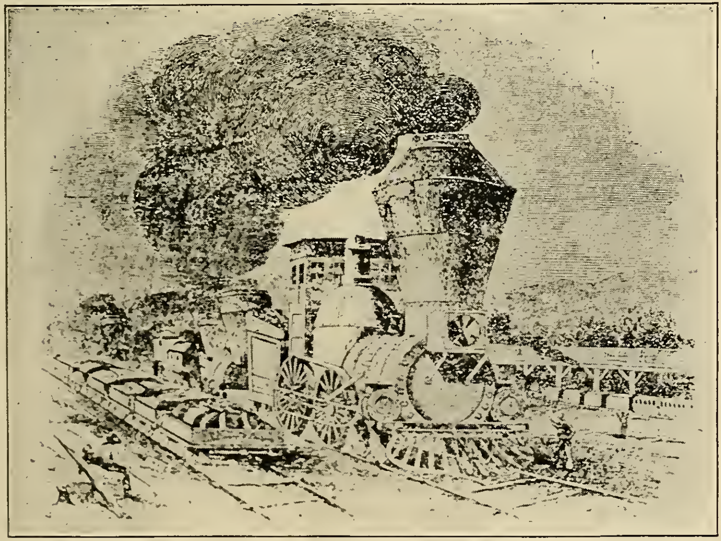
M. W. Baldwin.

About this time a number of locomotives were imported from England, and one was built at the West Point Foundry in New York in 1831. Mr. Baldwin completed a locomotive for exhibition in a museum, and the success of the model was such that he received his first order for a locomotive from the Philadelphia, Germantown & Norristown R. R. Co. In those early days it was almost a superhuman task to undertake such a work; mechanics were scarce, suitable tools were hard to obtain, cylinders had to be bored with a chisel fastened in a block of wood, while blacksmiths who could weld bars of iron 1½ in. in diameter were extremely few; therefore, Mr. Baldwin, although the designer had to do the work himself, and at the same time, educate such men as assisted him to do their work. The work, however, was prosecuted to the end, the locomotive was completed, and tried in November, 1832. This was the famous "Old Ironsides" engine, and at the time of its construction, thirty men were employed in the works.

The increased number of engines constructed by the Baldwin Locomotive Works, together with the number of men employed during 1832 to 1907 are as follows:

Year	*No. of Engines Built*	*No. Men Employed*
1832	1	30
1837	40	300
1854	62	500
1855	47	430
1884	429	2,377
1890	946	4,493
1900	1,217	8,208
1906	2,652	17,432

During the period 1832 to 1840 the number of men employed had gradually increased from 30 to 300, and the average weight of these locomotives was between 20,000 and 26,000 pounds, or from 10 to 13 tons. During the period 1842 to 1854 the number of men employed had been increased to 500.



An Early American Locomotive.
(From an old print.)

During the period 1855 to 1860 the principal engines which were constructed were those that are at the present time styled the "American, or Eight-wheel Type" of locomotive. From 1861 to 1865, which covers the period of our Civil War, trade being very much unsettled, there was, of course, a noticeable falling off in the building of locomotives; following this period of depression, much activity was shown and in 1866 the "Consolidation" type first came into use and the following year the "Mogul."

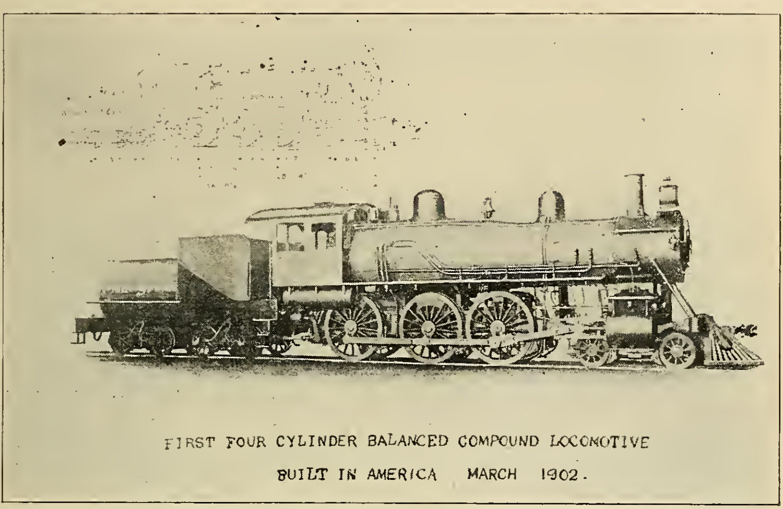
Mr. Baldwin died in 1866, and aside from having contributed more to the development of the steam locomotive as a complete unit than any other man of his day, he was also the inventor of many of the most important and essential details entering into its construction at that time, and many of which are still retained and in use at the present time.

A comparison of the Baldwin Locomotive Works, which consisted of Mr. Baldwin and a few handful of men in 1832, and the Baldwin Locomotive Works at the present day, which organization is based upon an annual output of 2,600 locomotives is as follows:

Number of men employed	19,000
Hours of labor per man per day	10
Principal departments run continuously, hours per day	23
Horse power employed (Steam engines)	12,138
Horse power employed (Oil engines)	4,850
Total horse power	16,988
Number of buildings comprised in the works	47
Acreage comprised in works (Philadelphia)	17.8
Acreage comprised in works (Eddystone)	184.8
Acreage of floor space comprised in buildings	63.2
Number of dynamos for furnishing light (Arc)	16
Number of dynamos for furnishing light (Incandescent)	7
Horse power of electric motors employed for power transmission (aggregate)	14,200
Number of electric lamps in service (Incandescent)	7,000
Number of electric lamps in service (Arc)	951
Number of electric motors in service	1,115
Consumption of coal, in net tons per week, about	3,000
Consumption of iron, in net tons per week, about	5,000
Consumption of other materials, in net tons per week, about	1,460
Approximate value of one year's output	$35,000,000

The American Locomotive Co. are about on the same basis of force and output.

The country in general was enjoying an unusually industrial boom with the incoming of the 20th century. The general prosperity resulting in extra demands for all kinds of transportation; the natural result was a general increase both in the number and capacity of both cars and engines. A special feature or departure, however, from the conventional lines, which had been followed in locomotive construction were noted in improvements; the inventions of Mr. Cornelius Vanderbilt, a mechanical engineer, received much deserved attention from the railroad and engineering world at that time; particularly so in connection with a new type of locomotive tender and fire-box, the first being applied to a ten wheel locomotive built for the Illinois Central R. R. and exhibited at the Pan-American Exposition at Buffalo, New York. The advent of the four cylinder balanced compound engine, however, so closely followed this, that a picture is herewith presented of the first engine of this latter type built in America. This was the 20,000th locomotive constructed by the Baldwin Locomotive Works, its completion being in February, 1902. The special feature was the balanced principle, together with the previously mentioned cylindrical tank, and fire-box, inventions of Mr. Vanderbilt. The tender design and construction is clearly shown in the illustration.


FIRST FOUR CYLINDER BALANCED COMPOUND LOCOMOTIVE
BUILT IN AMERICA MARCH 1902.

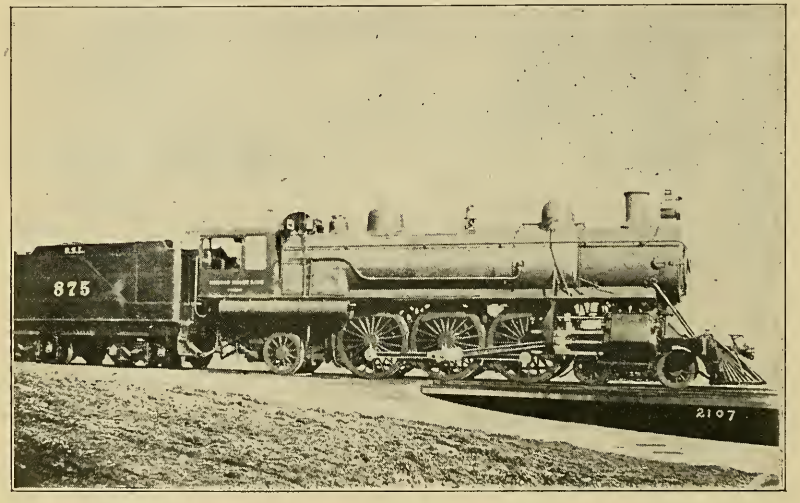
A Heavy Duty Modern Locomotive.

Following the completion of the first balanced compound engine, and the importance attached to its superiority over other types with respect to track maintenance, through the elimination, to a great extent, of the injurious effects of the hammer blow on the rails, its merits seemed to be recognized, and between the time of the construction of the first one, and the present time, there have been built approximately 370 which are in service on American Railways. The principal builder was the Baldwin Locomotive Works, although engines of this kind are also built by the American Locomotive Works, which have given excellent results both in actual service on the road and in testing plants.

One particular railway has in service more of these engines than any other, namely, the Atchison, Topeka & Santa Fe Ry. which has two hundred and fifty.

The one objectionable feature to this type is the crank axle, which has been regarded by some as its weak point. The materials and methods employed in manufacture however, have improved to such a degree that the axles are now made principally in built-up sections being composed of seven (7) pieces, which are pressed together in a hydraulic machine, the center member being cast steel. This form is heavier than the solid forged type originally used, but is less expensive to make, and should any part require removal, it can be replaced without discarding the entire axle, which seems to be a point in its favor.

Engines of this type have produced some remarkable records, both in speed and efficiency, the most noticeable of these was a balanced compound on the Chicago, Burlington & Quincy R .R., which during a series of tests against three single expansion engines, the compound developed 20 per cent more horse power than the other locomotives, making unusual time with a passenger train of twelve cars, weighing with the engine and tender 719 tons. None of the single expansion engines were able to equal this performance and subsequent tests carried out on that road gave about the same results.



Modern Type of Heavy Passenger Engine.

Following the completion of certain electric street railway lines and successful experiments with electric locomotives some seventeen years ago, it was predicted by some of the most eminent men of our country, that the steam locomotive's death knell had been sounded. In an authorized interview, one of the leading railway magnates at that time predicted that in twelve or fifteen years the steam locomotive would be pretty generally superseded by the electric locomotive, if not entirely relegated to the scrap heap. The opinion thus expressed was endorsed by many authorities of less prominence, including the daily press and a number of technical papers, with the result, that many were led to believe that the steam locomotive had reached the limit of its usefulness.

There were, however, a number who were not prepared to accept this conclusion; they had heard similar outbursts of enthusiasm on other occasions when some new device was presented with reasonable satisfactory results. Among those who recognized the fallacy of such views was one whom it might have been expected would have accepted the opposite opinion; this was Mr. Frank J. Sprague, whom it might be said, was the father and one of the principal promoters of electric railway transportation in America. The birth of electric railways really occurred at Richmond, Va., in February, 1888, and in an article by Mr. Sprague published in the July issue of the Engineering Magazine, 1895, or about seven years after the completion of the Richmond road, and at a time when the honors showered on Mr. Sprague, and the extravagant prophesies for electricity, and against the steam locomotive would have turned a less conservative man's head, Mr. Sprague among other things, in an able article on

"WILL TRUNK LINES BE OPERATED BY ELECTRICITY?"

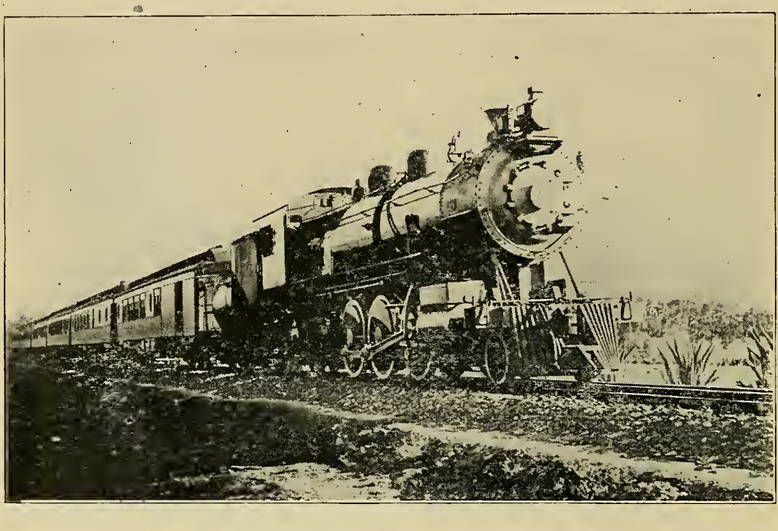
very modestly and intelligently reviews the subject, saying among other things:

> "That since the first line has been built, and put in operation, the United States, England, France, Germany and Italy have no less than 700 electric railways, covering 7,000 miles, and representing an investment of $250,000,000."

The very able analysis closed with a prophecy, which time has confirmed in every particular, and which I also quote:

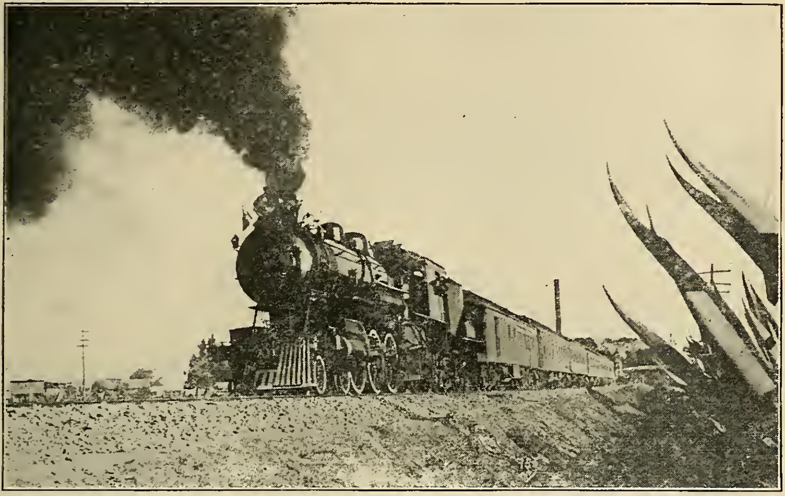
> "Let us lay aside then some of the visionary prophecies concerning electric railways with which probably no one has been more closely identified than myself; no one has greater faith in the electric railway than I, but its future is not in the wholesale destruction of existing great systems. It is in the development of a field of its own with recognized limitations, but of vast possibilities; it will cover such field to the practical exclusion of all other methods of transmitting energy; it will replace the steam locomotive on many suburban and branch lines; it will operate almost all street railway systems and elevated and under-ground roads; it will prove a valuable auxiliary to Trunk Systems, but it has not sounded the death knell for the steam locomotive any more than the dynamo has sounded that of the stationary engine; each has its own legitimate field, and will play its proper part in the needs of all civilization."

There are at the present time entering the city of Chicago some twenty-six (26) Trunk Line railways, operating with steam locomotives. These lines have an aggregate mileage of 90,285 or about 40 per cent of the total mileage in this country; 22,623 locomotives or 40 per cent of the total; 845,106 cars or about 42 per cent of the total, and with a valuation of $5,324,062,000 or a little over 31 per cent of valuation of all railways in the United States, which is placed at $16,936,150,204. These companies operate in the City of Chicago, with few exceptions, steam locomotives using bituminous coal for fuel, and not infrequently contribute to the evils chargeable to the smoke nuisance, in a manner shown by photographs taken of an engine in service wherein it is assumed that 150 lbs. of coal per sq. foot of grate area per hour is being consumed, with a loss of over 50 per cent of the fuel used. Such favorable results as are at times obtained in locomotive practice may be noted in the next photograph of the same engine, but as you will note, with almost an entire absence of smoke, although the engine in each case is performing the same service.


Locomotive, Doing Heavy Duty and Smokeless.

There are in service in the City of Chicago approximately 650 locomotives, and assuming that each engine consumes 5 tons of coal per day, we have the combustion of 3,250 tons of coal per day; if 1 per cent of this total amount of smoke and soot permanently adheres to buildings, structures, etc., or contributes to the death or destruction of trees, grass, flowers, etc., or to the injury of clothing, people's health, etc., then the steam locomotive, it would seem, stands properly arraigned under a very serious indictment.

However, before rendering a verdict, let us take evidence from both sides, after which we can better determine the proper degree of responsibility.



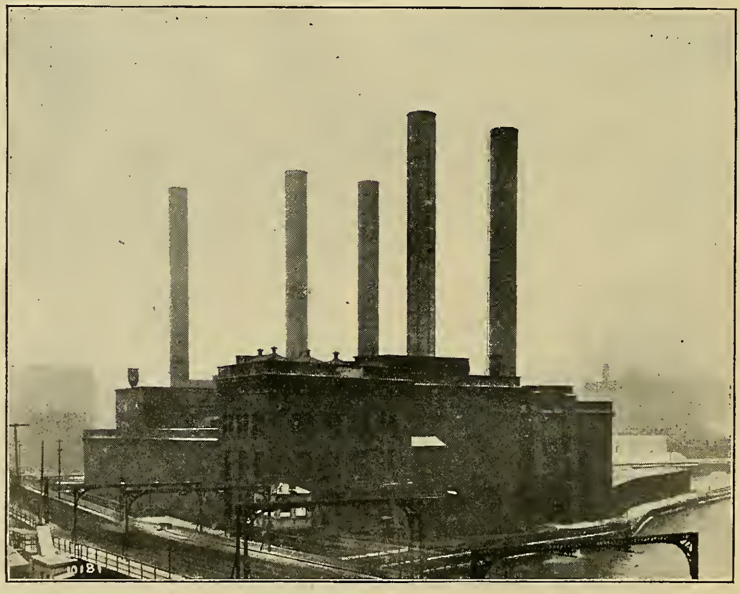
Heavy Duty Locomotive—emitting much smoke.

The Smoky Atmosphere of Chicago, largely due to Stationary Power Plants.

There are hundreds, and I may say thousands, of chimneys in Chicago daily contributing to the evils of the smoke nuisance, and which no one familiar with the subject will dispute. The public mind, however, has of late been systematically and thoroughly poisoned against corporations, especially railway companies, and on this account the author is inclined to believe that a proper division of responsibility has not been made.

There are approximately 1,129,567 tons per year pass off from chimneys as smoke or soot, and about 1 per cent of this quantity of smoke or soot adheres permanently to buildings, structures, etc.

I would invite your attention to photographs of chimneys wherein practically smokeless combustion is attained, while others show the real origin of the smoke nuisance. A comparison of the relative quantity of fuel used in the city by locomotives and that by stationary plants will show plainly the proportion each contribute. This should, however, be studied in connection with such conditions as surround each.

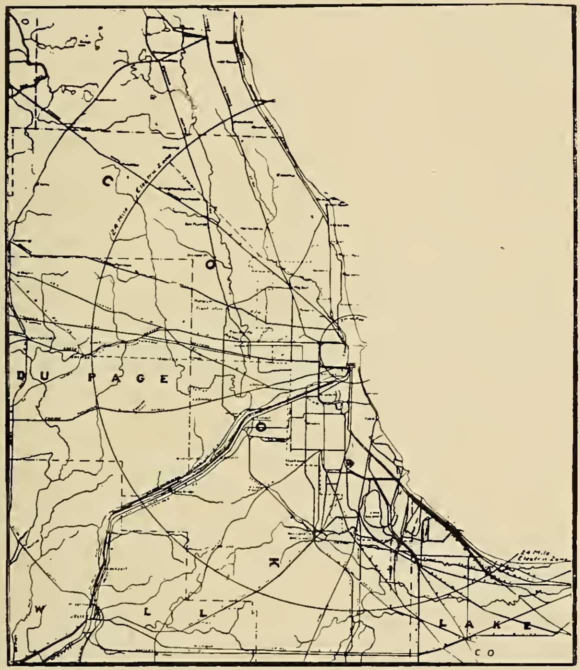


A Smokeless Power Plant in Chicago.

A division of responsibility serves to indicate on whom the burden of relief should rest with respect to abatement, and in this connection, it should be remembered that the schedule of miles, engines, cars and valuation of railways entering Chicago, also applies to many other cities and industrial centers; in other words, many of these lines have small interests here as compared to the sum total of their interests at other points, while the stationary plants are each one a unit in Chicago's sum total of assets, and in which we have seen that the steam locomotive only contribute 13 per cent of the smoke nuisance.

SUGGESTED REMEDY.

The author suggests consideration of an electric zone and submits tentative plan from which, as will be noted, all steam locomotives using bituminous coal will be, after a certain date, prohibited from entering, in the residence districts, steam locomotives regardless of the kind of fuel used should be reduced to a minimum in numbers, on account of the noise their operation produces.



Suggested 24 mile Electric Zone—within which no steam locomotives are to be used.

In the matter of stationary plants, which seem to be the arch criminals in this indictment, the author would invite attention to the view of a smokeless chimney, which is within range of every day operating conditions, except when first kindling fires, which is a very small fracton of the time. There are may plants, however, which continually produce smoke, and as a step toward an effective and positive remedy, the police power in conjunction with proper engineering talent and practical experts, should regulate those plants, which are to be so designed and constructed as to be operated without emitting smoke; those outside of this qualification should be given ample time to either put in proper plants, or arrange to secure heat, light, electric current or power from some central plant, to be provided either by the city, or under its supervision, to the end that the smoke nuisance may be effectively and permanently abated without injury to any individual, corporation or industry.

Wonderful progress has been made in the development of electric railways since Mr. Sprague's very conservative prophecy of twelve years ago. A report showing in a general way this development from 1888 to 1902 is as follows:

Companies	987
Mileage	22,576
Cost of road	$2.167.634,077
Number of Employees	140.759,000
Number of Cars	60,290,000
Number of Passengers	4,774,211,904

In addition to this there has been a still greater development since 1902 than recorded prior to that time. Notable among these has been the interest shown by steam railway companies in the matter of electrifying certain sections of their lines.*

Notwithstanding the progress of electric transportation (as above outlined) we should not lose sight of the fact, that the steam locomotive has made greater strides in the matter of increased numbers, together with marked development or refinement both in the manufacture and the operation of the machine. Thus time only tends to confirm the truth of Mr. Sprague's prophesy as to the limits to which electricity and steam are respectively confined.

A very interesting and instructive paper was presented by Messrs. Stillwell and St. Clare Putman at the meeting of the American Institute of Electric Engineers in New York City, January 25th, 1907. Much valuable and interesting data was brought forth and analyzed in a way that could not but arouse much interest in this all absorbing question. Their summing up showed that in a general way the aggregate cost of operation of steam railways of America based on the expenses of 1905 would be reduced about $250,000,000 by changing from steam to electricity. The proposition to electrify all of the steam railways of America is not, in the author's opinion, worthy of consideration, as it would be a practical impossibility from a financial standpoint; he would question the wisdom of undertaking changes of such magnitude when it is easy to determine that in order to realize the economies shown, it would be necessary to stand such unusual losses in other directions, and it would impose additional financial burdens of such magnitude that in the majority of cases bankruptcy would follow.

It would seem, however, a conservative proposition and one that would not impose unnecessary financial burdens on the people, or present any unusual complex engineering problems, to consider the introduction of electricity as a means of transportation in and adjacent to all large cities or commercial centers where the demand or the conditions are similar to those, which have been and are being successfully met in New York City.

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*(See Mr. Arnold's Annual Address, January 19th, 1907.)

Chicago is suffering more from the smoke nuisance than New York ever did. It is also suffering from lack of adequate transportation facilities, and the substitution of electricity for the steam locomotive would provide relief in the matter of transportation; it would contribute relief with respect to the smoke nuisance in proportion to the degree of its responsibility. Both problems are easier of solution in Chicago than they were in New York, presenting no engineering or financial difficulties, which can not be reasonably and satisfactorily met, and it would seem there is really no excuse for farther delay in securing necessary relief in this direction.

In order to illustrate more forcibly the probable future requirements in the matter of transportation let us review the increase in population for some years past, and at the same time observe what conservatively reliable estimates show for the future.

The increase in population in Chicago up to 1892 was about 11.2 per cent, since then, and up to 1901 less than 5 per cent. An average from 1837 to 1892 was 8.6 per cent, in 1902 estimated 2,000,000 population, and at 5 per cent compounded, it is fair to assume the future population will be about as follows:

1910	2,750,000
1920	3,250,000
1930	3,750,000
1940	4,500,000
1950	5,200,000

This is on the conservatively low average of 3 per cent, while if the national and local conditions governing the growth of Chicago were to average in the future exactly as they have in the past, then the population would be at the following rate:

1910	3,500,000
1920	5,500,000
1930	7,750,000
1940	10,250,000
1950	13,000,000

It is hardly reasonable to assume that the latter figures will obtain; under the former figures however, which are very conservative, it is not a great while until Chicago will be a city of 5,000,000 people, and as it is already over-crowded in the business districts with inadequate transportation facilities, which conditions are becoming more aggravated every day, and it is darker than London most of the time from smoke and soot, it is high time that Chicago should wake up not only to its present, but future conditions, and make provision for relief along these lines.

CONCLUSIONS.

This review of the Evolution of the Steam Locomotive, embracing as it has certain correlative features of the instrumentalities of transportation, past, present and future, involving questions of Finance, Engineering and Civic Pride, has for its primary object, the hope of aiding in a limited degree such efforts as has been made or may be under consideration, calculating to improve transportation facilities and beautify the city of Chicago.

On the basis of our present population in the United States, and the transportation facilities to meet our requirements, it is not exaggerated prophesy, but a conservative temperate estimate based on facts that in a few years we will be a nation of 150,000,000 people, and that the Mississippi Valley will be the home of 80,000,000 people.

Should transportation facilities be increased during the next twenty years in proportion to the lowest possible estimate, together with what is at present needed, the rail and water map, may at that time reasonably be assumed to show 400,000 miles of main line and terminal facilities, and several thousand miles of canals and canalized rivers; the latter to include a deep waterway from the Lakes to the Gulf. The increased railway mileage would be approximately 170,000 miles, and the increased number of locomotives necessary for its operation, based on present ratio of miles per engine, would be about 56,000; of this number at least 75 per cent, it is reasonable to assume, will be steam locomotives, which would bring the grand total up to or above the 75,000 mark with possibly 20,000 to 25,000 electric locomotives, or a grand total of 100,000 locomotives.

The cost of the above outlined improvements and additions may be conservatively estimated at $16,000,000,000 or an amount equal to the present valuation of all railway property created or acquired during the seventy-seven years of the period, 1830 to 1907.

Certain prominent railway men have been criticised for their outspoken views as to the country's future requirements in the matter of transportation. In the map shown all present railway lines are eliminated, the heavy lines indicate tentative location of approximately 12,000 miles of broad gauge trunk lines 6½ to 7 ft. gauge, between the principal commercial centers; on these lines trains of special design and construction would handle 8,000 to 10,000 tons without interruption, and thus the prophesy of such men as Mr. E. H. Harriman and Mr. James J. Hill would not only be fully realized, but another distinct epoch in steam locomotive design would be added to its present interesting history.

A glance at the graphic chart not only shows past and present ratios of population, railway mileage, locomotives, cars, etc., but from this it can be seen that predictions as to our future requirements are conservative, and it should be specially noted that Chiacgo, the center and recognized mistress of the vast area tributary thereto, will if she keeps pace with the wheels of progress, profit more than any other point in the United States from such improvements as must necessarily be made.

Chicago however, can never hope to be even reasonably clean or to enjoy efficient interurban transportation service while she tolerates the smoke nuisance, from 650 steam locomotives and about twelve thousand (12,000) chimneys, of power plants burning bituminous coal.

The electrification of all steam railways, together with similar reforms in all stationary steam plants; or in event of complete success not being practical or feasible, then the city should install power, heating and lighting plants to supply heat, power or light at a reasonable cost to those who either can not or will not install and operate a smokeless plant; this is to the end, that Chicago's well deserved fame as the leading commercial and business city of the Mississippi Valley may be enhanced by taking rank as the most beautiful city.

The author is glad to acknowledge the kind assistance of Messrs. Bion J. Arnold, Frederick A. Delano, F. H. Burnham, Angus Sinclair, Slason Thompson, The Franklin Institute and others.

DISCUSSION.

Mr. P. Junkersfeld M.W.S.E. (Chairman): I feel sure that I voice the views of all those present when I say that we have listened to an exceedingly interesting and profitable paper, and which refers to developments almost incomprehensible for the period included, especially when we think that within the life of a number of men now living locomotives were built by jewelers and watch-makers. Mr. Symons has brought us down to the time when a single locomotive manufacturing company turns out six locomotives per day for every day in the year, including Sundays and holidays.

It might be interesting, in passing, to say that Mr. Hedley, whom he mentions as the inventor of the "puffing Billy," has a great grandson, who today is General Manager of the Interborough system of transportation in New York, which carries something over a million passengers per day. This is simply another illustration of the very rapid advance in transportation within the last century.

Mr. Symons has furthermore told us a few of our faults as residents of Chicago; also some other things which ought to appeal to us, if not to our civic pride, at least to our civic ambitions and possibilities.

Mr. W. L. Abbott, M.W.S.E.: I think, in company with the rest of the audience, I have listened to this paper with considerable uncertainty as to where the author would finally arrive. When he started in I expected to see the end of the locomotive before he finished, but when he did finish I was a little uncertain as to whether steam locomotives were to be replaced by electric, or whether the electric locomotive had reached the zenith of its development as far as replacing the steam locomotive is concerned. If I got one clear idea from the paper—and there is no criticism on the arrangement of the paper whatever—it is that electric propulsion on railways should replace steam in densely populated centers, only like that, for instance, within 25 miles of Chicago.

Then the author goes on to show that we are within an epoch of great increase in population, wherein the railway business of the country, and particularly of the Mississippi Valley, will undergo great development, and if the electric locomotive has any mission other than that of smoke abatement, I cannot understand why it will not have its place all over this Mississippi Valley, which the author says will be populated with more than the present entire population of the United States.

The limitation to the general adoption of electric haulage is the number of trains per hour, you might say, on the road. If, with this increase of business in population, there comes a corresponding, or even greater, increase of railway business, that objection will be met.

The matter of transmission of electrical energy is another drawback in the way of substitution of electric for steam transportation. This is being gradually and rapidly overcome. Long distance electric transmission is stretching out its lines further and further every year; voltages are being raised; insulation is being improved; aerial lines are being more substantially built, and I consider that the matter of extending and maintaining aerial lines for the transmission of power is now no more of a problem than was the maintenance of telegraph lines at the time the telegraph system was first introduced. With the extension of power transmission to distances, we will say, of 200 to 300 miles, it will readily be possible to locate power houses at the mines and transmit energy all over the Mississippi Valley and all over the country east of the Alleghenies—at least nearly so—without transporting coal on railroads. I do not know what fraction of the freight business of the railway companies now consists in hauling their own coal, but it must be considerable, and to relieve the railway companies from this amount of tonnage would make their equipment at once available for more profitable business, since the haulage of coal, is about the cheapest work which they do.

The coal economy of locomotives, while it has been considerably improved by the introduction of the compound locomotive, is necessarily limited, and must always be far below that possible with power houses equipped with large boilers and large steam turbines. Power houses are able to use an inferior quality of coal at the mine which is not suitable for any other business. Railways require the best grade of coal. If the railways could obtain their fuel at a price, we will say, about one-third of what they are now paying per ton mile, I presume the saving would be equal to the money which is paid out in dividends. Looked at from these points of view, I cannot but consider that the prospect for the permanency of the steam locomotive is not bright, and the passing of the steam locomotive may be nearer than the author would have us believe.

Referring to the smoke problem, particularly within the city of Chicago. The author says, in effect, that because the locomotives burn about 15 per cent of the coal burned in the city, they make only 15 per cent of the smoke. It has been my observation for sometime that the amount of smoke emitted by a plant has little, if any relation to the diameter of the chimney. A stack burning a bushel of coal an hour may make more smoke than a stack whose furnaces consume several tons. I cannot agree with him in the statement that the locomotives have made very little impression upon the general dirty condition of the atmosphere of the city.

Mr. Junkersfeld: Following the thought which Mr. Abbott and the author have expressed, it might be interesting to note that the New York Central Railroad Company is operating all its passenger trains within the electric zone with about 10,000 k.w. of power-house demand. Using that as a basis, it has been calculated roughly that passenger trains within the 24-mile zone, as shown by the author, could be operated with something like 50,000 k.w. That means that all the passenger trains within that zone could be operated by three or four units in a large modern power house.

Mr. J. N. Hatch, M.W.S.E.: The author has given us a very interesting forecast of what will be the demands for transportation in the future, with the great increase in population which he predicts. But the implication seems to me to be that the steam locomotive will continue to increase and will at that future date, which he has considered, bear much the same preponderance of importance in transportation which it holds today. As to the truth of this prediction I have very grave doubts, if a curve were drawn showing the relative importance of locomotives as a factor in the transportation problem of the country, I am not sure but we have already reached the highest point of that curve. I believe that the importance of the locomotive as an economic factor in this country has already reached its zenith. The question of whether the railroads will change over to electricity or not, is bringing out some interesting discussion. I think the problem hinges, not so much on whether or not they can afford to electrify or whether they are willing to go to the expense, as on the question as to whether they can afford *not* to electrify. This question it seems to me hinges on whether or not the electric railway will be profitable. If electric railways are profitable, the railroads can do as they please about changing over; if they do not, electric railways will be built, and in the last analysis, the railroads will have no choice in the matter; it will be change or go out of business.

Another thing which it seems to me is going to have a great bearing on this is the convenience of the electric railway over the steam road. It will be only a short time now until electric roads will be in operation from Chicago through to Cincinnati, Louisville, Detroit, and other such cities, and it will be but a few years until almost all the present one-night runs of the steam locomotive will be made by the electric railways. At the present time a great many of those steam roads kill time all night in order not to arrive at the destination until a reasonable time in the morning. This is especially true of such points as Detroit and Indianapolis. There is no question but that the electric roads, even in the present state of the art, can make such runs in one night, and if they put on sleeping cars and become popular, they stand a good chance of taking away all sleeping car business from the steam roads. It would not be at all surprising to me if sleeping cars run on the electric railways—especially the one-night runs—would drive the steam car, for that distance, practically out of business.

Several years ago I worked on the Third Avenue cable line in New York City, and they spent a tremendous amount of money putting in the cable, but in five years' time they did not hesitate to change that over to an electric line. In Pittsburg and Cleveland they blew out all the cable work with dynamite, and put in electric lines. Certainly these cable roads cost as much as steam roads and if the cable companies did hesitate to do a thing like that when they found they had to, I do not see but that it is simply a question whether or not the electric roads will pay, that will decide the matter.

Mr. A. Bement, M.W.S.E. (by letter): Mr. Symons has raised the question of responsibility for smoke emission. It is a very interesting subject and one well entitled to more careful consideration than it has thus far received. It is and has been the practice to attach the entire blame to the individual firm or corporation owning the smoky chimney, and it is against this class and no other that legislation is directed, when as a matter of fact the furnace apparatus is designed and built by others. It is also true that the owner is compelled to depend upon the services of members of the community, who in the capacity of firemen, operate the furnace; thus we have a situation wherein an architect, a consulting engineer, a manufacturer of furnaces, and a furnace operator as well as the owner of the chimney, have contributed to the production of smoke, but of these, four classes are immune, the owner taking the blame and punishment for all of them. Under present conditions, of course, there is no other way, and while the owner is in very large measure an innocent victim of circumstances, yet it is through him that these other people are reached in only a feeble and indirect manner; thus the smoke suppression campaign naturally works at rather a low efficiency owing to the high resistance offered by the medium through which its efforts are expended.

Strange as it may seem, the most important results in the way of smoke elimination have come through changes which have been due to other causes rather than that of the elimination of smoke itself. For example, a factory will go on for years using apparatus that not only wastes a large amount of money but pollutes the atmosphere, owing to incomplete combustion, until it is desirable to install a new power plant, at which time, often by accident or the result of personal prejudice, either a Sterling with its long ignition arch or a Heine boiler with a tile roof are purchased and fitted with chain grate stokers, with the result that the plant may become a smokeless one.

As far as locomotive smoke is concerned, it is probable that no decided cure will be effected until electrification of that portion of the various railroads which enter the city is accomplished. Thus electricity which has done so much up to the present time in eliminating the smoky chimney, will be an increasingly important factor in the future, with the result that the installation of small steam plants will become still less frequent.

CLOSURE.

Mr. Symons: The remarks of Messrs. Abbott and Hatch are very much to the point, and bring out some good features bearing on certain phases of steam and electric railways. I regret that other speakers were not in attendance to discuss the question from other standpoints, and bring out additional information, which it was contemplated would be of much value.

Referring to the percentage, or proportion of smoke emitted by locomotives as compared to the total, I will say, by way of explanation, that the number of locomotives used in my calculation was the number that is reported as being assigned to service in the Chicago district. Included in these are switching and work-train engines; many of them being outside the city limits, a portion, or all of the time. There are a certain number of engines termed "road engines" taking trains from passenger depots, or freight yards, that contribute some to the smoke nuisance, and I assumed for the purpose of my calculation that the number of road engines, which enter the city each day to either deliver, or take out incoming or outgoing trains, would about off-set the number of switch engines assigned to the Chicago district, which were outside of the city, and thus did not contribute to the smoke nuisance. Taking this number of locomotives as a basis, I then assumed they would consume 5 tons of coal per day per engine, while in practice they do not use this amount. The records from some of the most prominent lines running out of Chicago, having in service the largest modern switch engines, show that these engines burn on an average, less than 4 tons of coal per day; therefore I think that in my calculation a degree of liberality was shown, which would more than off-set such credits as might be due to chimneys of stationary plants, which are smokeless. In the absence of this explanation, however, I think Mr. Abbott's criticism was quite proper, and to the point.

In the matter of extensions of electric railways referred to both by Messrs. Hatch and Abbott, I think it is quite true, that lines will be extended more in future than they have in the past until the entire Mississippi Valley from the Rocky Mountains to the Alleghenys will be gridironed with electric lines. The question of transmission of energy has, I think, been satisfactorily solved. The figures quoted, however, as to our probable future requirements in the matter of steam and electric railways were arrived at by taking into consideration all of the features mentioned by the previous speakers, favorable to the development of the electric railway. It also took into considration our increased population for the next twenty years, and the necessity of meeting their views and actual needs in the matter of transportation, and while I assumed the development of the electric railway would be as great as that anticipated by others, I have not reached the conclusion, and am not prepared to admit, that this increased electric development will in any manner interfere with the development of steam railways into new countries; neither do I think it will result in driving any of the present steam railways out of business in the older settled communities. Take for instance, present day conditions in Ohio, Indiana and portions of Illinois. Indianapolis is today considered as being the best provided with transportation facilities of any point in the civilized world, there being a veritable net work of electric railways diverging from, or entering, that city, and connecting with prominent cities within a radius of 200 miles. It is a fact, however, that during the development of this net work of electric railways, that the steam railways in operation in this same territory have added enormously to their equipment, both in the number of freight and passenger cars and locomotives. There are more steam locomotives in service today on the lines most closely paralleled by these electric railways than there were before the elctric railway was constructed, and the steam locomotives are, as a rule, about twice the capacity of those in service twenty years ago, which is equivalent to about four fold increase in steam transportation facilities. Our increased population throughout the country will result in a repetition of these conditions over almost the entire area between the Alleghenys and the Rocky Mountains, and in addition to this, there must necessarily be thousands of miles of canals and canalized rivers providing for transportation of low grade freights, such as coal, ore, lumber, etc.

We have ceased to be a frontier country, except in its application to some of the most remote districts that are still unsettled, and in those districts the steam locomotive will continue in the future, as in the past to be the "pioneer," which will penetrate, open up, develop and populate these unsettled areas, after which the electric lines will come just as it has in the older states and communities.

It was only a few years ago that the merchant or tradsman went to market twice per year to purchase goods for his customers; today through the middle states where the transportation facilities above mentioned exist, he goes every week and sometimes oftener, purchasing goods in small quantities and which he frequently insists on having delivered to him the next morning.

This furnishes business for the electric railway and for the steam railway combined, and with several hundred thousand tradesmen in the Mississippi Valley with several million inhabitants depending upon them, it can easily be seen that the construction of both electric and steam railways will not likely be on a sufficiently broad, or liberal scale to meet the requirements of the people, and that there is absolutely no danger at the present time of one injuring the other, as they will both probably fall short of meeting the requirements in many cases. The only field of probable controversy is in large cities, where it is not a question of supremacy or of a survival of one as against the other from a financial standpoint, but a question of meeting a condition in which steam locomotives are unsuited and electric propulsion is not only desirable, but necessary. The question of relative cost is a secondary one. Therefore, to provide facilities for a nation of 150,000,000 people, which is close at hand, (and we have the official statement of the census bureau in Washington that we will be a nation of 900,000,000 people in 134 years) we will have to commence building new steam railways, provide second, third and fourth tracks for existing lines, possibly construct ten to twelve thousand miles of broad gauge steam railways with specially designed equipment, and increase the mileage of canals, canalized rivers, including a twenty foot waterway from the Lakes to the Gulf. This work should be prosecuted as fast as funds and labor can be provided. The electrification of trunk lines to be considered for terminal facilities at all large cities like New York, Chicago, St. Louis, Pittsburg, Cincinnati, Cleveland, Buffalo, etc. This, not only with a view of eliminating the smoke nuisance, but in order to provide more efficient train movements within the city limits.

It is not extravagant to prophesy that some of the present complex problems of transportation, and many future ones, may find solution in improved and increased instrumentalities of transportation of such a character that the purchasers' requirements may be met on a basis more in harmony with the service rendered than at present. Passengers of limited means, and not in haste, should not be required to pay the same rate as those of wealth, who demand, and willingly pay for the service of high speed and luxurious trains; the same principle may be well considered with respect to freight movements. In the years to come it is fair to assume there will be provided combined facilities to handle the commerce of the nation that will embrace waterways and additional tracks for low grade traffic, electric lines and high speed tracks for fast freight and passenger trains, and electric locomotives in most all large cities, and in many cases plying between large centers of population.

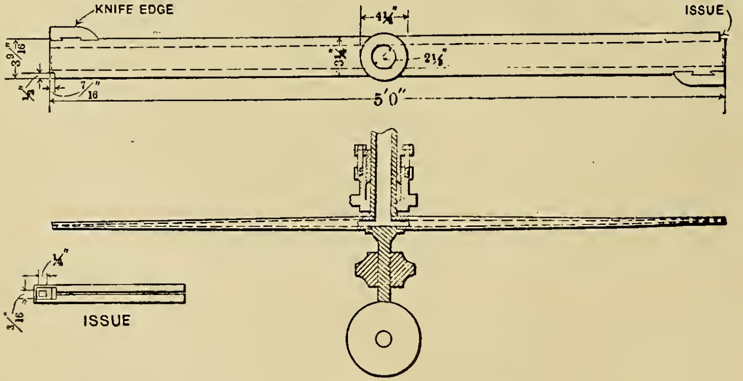
STEAM TURBINE DEVELOPMENT

Prof. J. C. Thorpe, m.w.s.e.

Presented May 6, 1908.

So much has been written during the past few years relating to the various phases of steam turbine engineering that one is confronted by a Herculean task, who proposes to present anything particularly new to an assembly of engineers, many of whom have been closely in touch with steam turbine development and operation. Thus, it was without a particular intention of presenting new thoughts that this paper was prepared, but rather of gathering together from various sources some of the facts developed during recent years and compiling them in convenient form for consideration.

Among the noteworthy facts that impresses itself upon the mind of the investigator of the development of steam turbines is the very close resemblance of the earliest types to many of the present day machines that are proving such efficient prime movers in our power stations of both large and small capacity. In order to observe this fact, let us turn aside from the limitations of our subject for a short period to consider some of the more prominent inventions of the early day. Professor Storm Bull, now deceased, in the presentation of his paper before this society in June, 1905, noted the beginning of steam turbine practice in the year 120 B. C., when Hero's Aeolpile was operated. In this machine we note the purely re-active steam turbine. In 1831, in Buffalo, New York, Mr. William Avery constructed and operated what is known as the Avery steam turbine, which was similar to the old Hero engine, a reaction turbine in the strictest sense. Steam enters the hollow shaft, passes to the ends



Avery Reaction Wheel.

Fig. 1.

of the hollow arms, where it issues at an enormous velocity. This machine for some time operated in a saw mill in or near Buffalo where it displaced a reciprocating engine. The excessive air friction and the erosion by the wet steam necessitated frequent and expensive repairs which eventually caused its abandonment.

In 1629, an Italian inventor, Giovanni Branca, published a book in Rome entitled "The Machine." In this book Branca described "The Branca Impulse Steam Turbine." In this machine a jet of steam is made to issue from the mouth of a negro's head, serving as a steam generator and impinge against the blades of a large wheel geared to a small stamp mill. This was the beginning of the now very popular impulse type of turbine. In 1884, De Laval first published the results of some of his earlier experiments and applied for patents on the De Laval turbine. This simple impulse turbine is one of the popular types today for small powers and it is not difficult to trace the suggestions of the Branca turbine through history to this highly efficient machine.

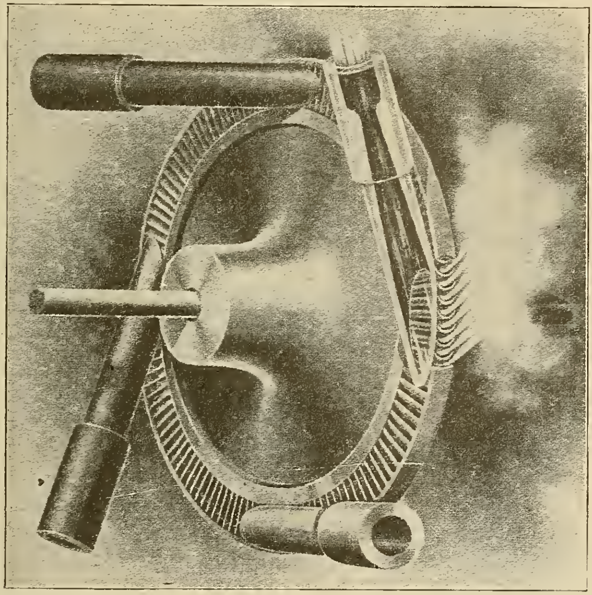
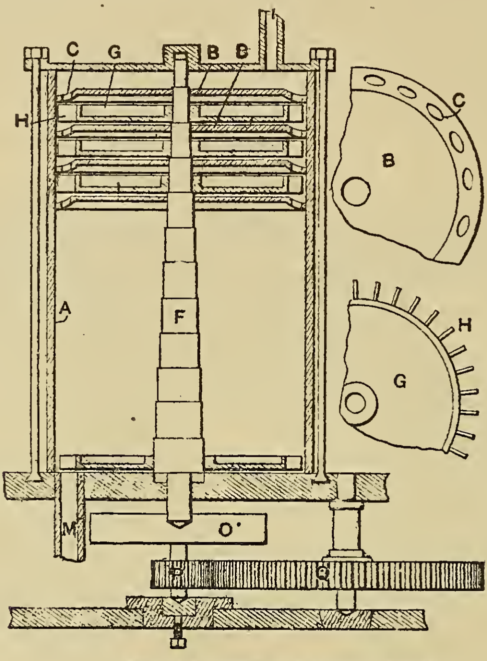


Fig. 2. The De Laval Turbine

Many of the inventions of recent years have been as visionary and impracticable as the inventions of Hero and Branca. However, there are records available of a few inventions which were the forerunners of the successful turbines of today, and which the writer believes would be of interest to consider at this time.

It was early understood that the enormous steam velocity and reulting peripheral speeds of the simple reaction and impulse wheels presented a great obstacle which must be overcome before the steam turbine would be of any considerable value, industrially. In 1827, Real and Pichon, Frenchmen, patented a compound impulse turbine that attempted the desired speed reduction by distributing the drop in pressure through a number of stages.



Real and Pichon Compound Turbine.
Fig. 3.

Experiments upon the flow of steam through variously shaped converging and diverging nozzles occupied the attention of many steam turbine experimentors. In 1838, one, Leroy, first published the results of such experiments and applied for patents on the Leroy reaction wheels.

There were special applications of the Avery reaction wheel mentioned above. The results of Leroy's experiments have been repeatedly verified by investigators during recent years.

It is interesting to note the numerous inventions of the earlier day failed to take any account of the increasing volume resulting from the drop in pressure from stage to stage, although the desirability of compounding was early understood as has been shown.

In 1848, United States patents were issued to one, Wilson, who occupies a prominent place among early steam turbine investigators. His most interesting and valuable invention immediately suggests the Parsons type and may be said to be the forerunner of that most excellent machine. Wilson was the first inventor to establish a claim based upon the increasing volume resulting from the distributed pressure drop.

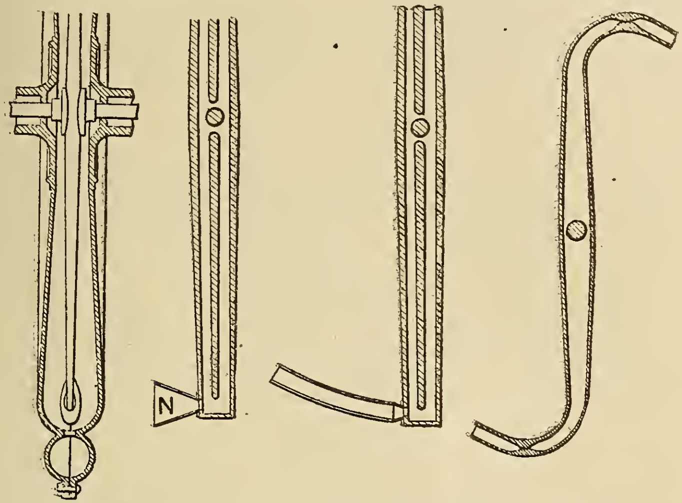
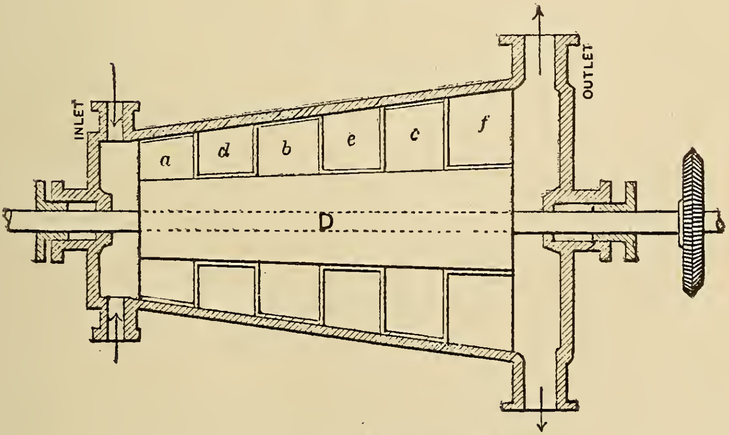


Fig. 3. Fig. 4. Fig. 5.

LeRoy's Reaction Wheels.

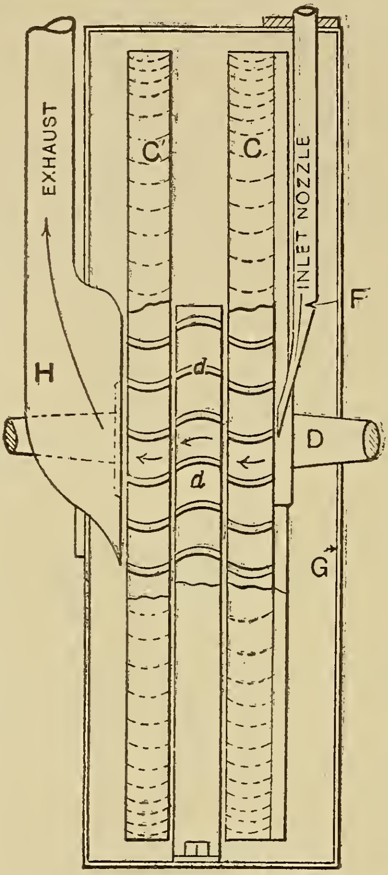
Fig. 4



Wilson's Compound Turbine.

Fig. 5.

In 1858, patents were secured by John and Ezra Hartman, the similarity of which machine to the modern Curtis turbine is immediately noticeable. The steam is expanded in the inlet nozzle and inpinges alternately upon revolving and stationary blades, no attempt being made to increase the velocity or reduce the pressure while passing through the sets of blades.



Hartman's Compound Impulse Turbine.

Fig. 6.

Another interesting invention in this connection is that of Moorhouse, in 1877. This machine, very similar to the present Hamilton-Holsworth turbine, built by Hooven, Owens and Rentschler, Hamilton, Ohio, which is of the impulse multi-stage type.

In 1885, patents were issued in several countries, covering the invention of a compound balanced reaction turbine, to Hon. C. A. Parsons, whose name from this date has been inseparably linked with steam turbine development. His first invention, Fig. 7, is very interesting, showing Parson's conception of the importance of the prin-

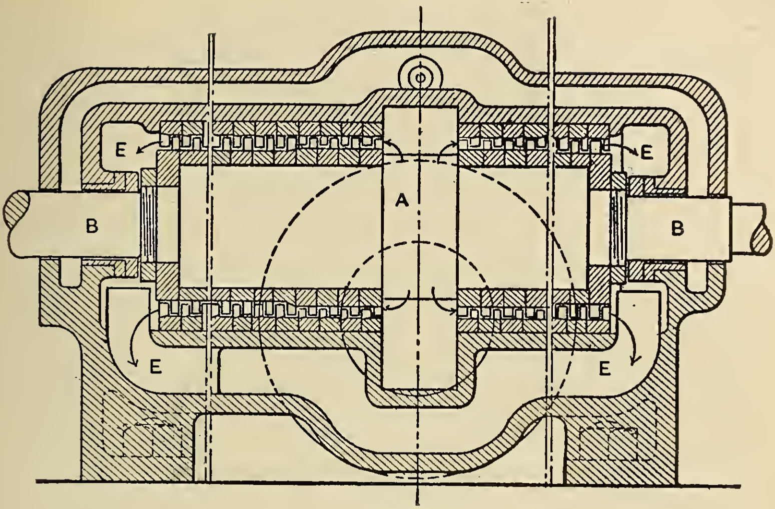


Fig. 7.

ciples of compounding and of the lateral balancing of horizontal machines. Among the other prominent features of this machine still approved and applied in the most modern design, are elasticity of bearings and forced lubrication. It may be said that Parsons was the first inventor to place the steam turbine on a commercial basis.

In 1889, De Laval, whose name is closely linked with that of Parsons in steam turbine development, secured his patents on the present expanding nozzle used with the De Laval machines. A patent on the expanding nozzle as applied to injectors had been issued twenty-five years before, but it remained for De Laval to apply it to the impulse turbine.

Much experimenting has been carried on and many patents secured quite recently upon various applications of Pelton Wheel buckets to steam turbines. The earliest patents issued in this connection were dated 1894, when J. T. McElroy and Professor A. Rateau received American and English rights, respectively. Defects in the design and construction of McElroy's turbine prevented its commercial application, but the simple impulse machine with Pelton buckets, of Rateau, attained some prominence before it was superceded by the multi-stage type. A general view of the rotor of the simple Rateau turbine, is shown in Fig. 8.

In view of the fact that the application of Pelton wheel buckets is the subject of much discussion and experimentation. it will be interesting to note the arguments presented in favor of their use. These arguments are presented in the light of objections to ordinary blading, which are:*

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*"Steam Turbines," by L. G. French.

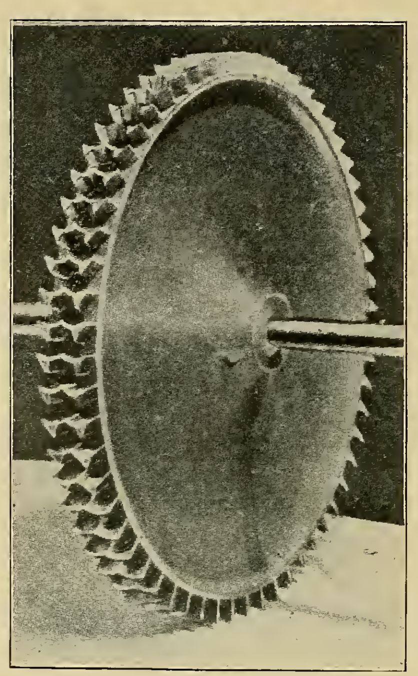

Fig. 8.

1. Increases the number of buckets at least five times.
2. Distorts the angle of reaction from 15 to 30 degrees in order to secure clearance.
3. Makes necessary the side application of the steam jet, thus increasing lateral stress and vibration.
4. Augments fluid friction.

Among the other turbines of more or less prominence, both in this country and abroad that use the Pelton bucket are, the Riedler-Stumpf of Berlin, the Zoelly and the Kerr.

The Riedler-Stumpf wheels were invented by Professor Stumpf, who was assisted in their development by Professor Riedler. A wheel and nozzle ring of this machine is shown in Fig. 9. It will be noticed that the nozzles, which are of the De Laval general type, extend completely around the periphery of the nozzle ring. Subsequent patents covered the return guides that were used to redirect the steam issuing from the wheel a second time upon the blades.

The first patents on the Zoelly turbine were taken out by Heinrich Zoelly in 1900. They set forth in particular the construction of a multi-stage turbine, with one rotor only, in each stage and a particular construction of the wheel disks. The arms, if they may be called such, were machined for a considerable part of their length and ended in the Pelton buckets, as shown in Fig. 10. The larger Zoelly

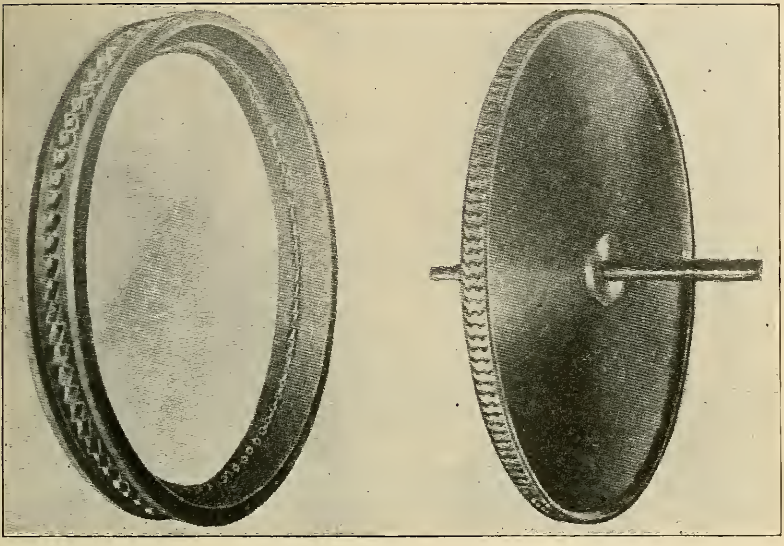

Fig. 9.

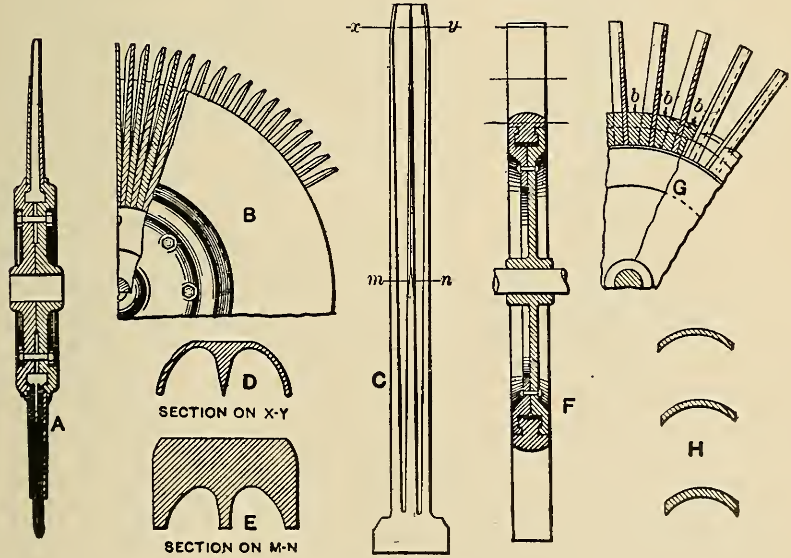

Fig. 10.

turbines are built in two sections, a high pressure and low pressure section, the steam passing from the high pressure to the low pressure side through steam passage in the turbine base.

The Kerr turbine is built by the Kerr Steam Turbine Company of Wellsville, New York. It is an interesting machine in the field of small non-condensing units of smaller powers.

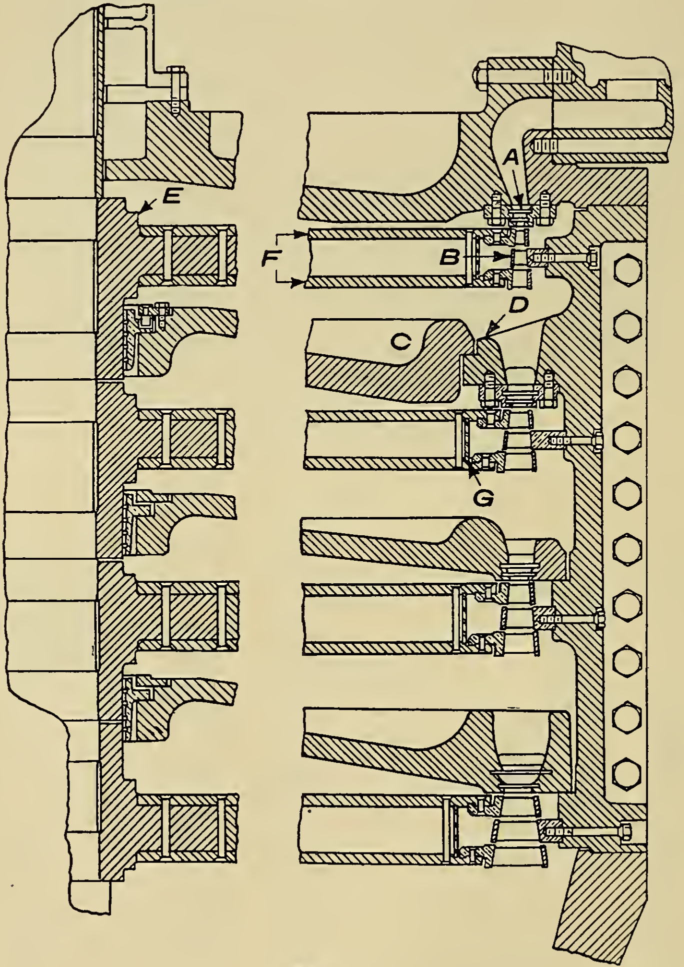

Fig. 11.

In 1896, Mr. C. G. Curtis took out a group of patents covering the important principles of construction of the Curtis Turbine, manufactured by the General Electric Co., of Schenectady, New York. The most significant feature of Mr. Curtis' claims was the application of the system of diverging nozzles with the compound wheel. Other inventors had applied the results of expansion that could take place only in a diverging nozzle but no invention had been previously made of the apparatus itself. In Fig. 11, is shown the present preferred arrangement of nozzle and moving and stationary or intermediate blades.

In the preceding discussion, the more important inventions that have influenced turbine development have been considered. That the principal difficulties in design and construction were early recognized is very apparent. From the earlier days, designers have endeavored to reduce the energy losses to a minimum and it is this desire that inspires present day designers who have brought the steam turbine to the prominent place which it occupies in the list of prime movers. The energy losses, mentioned with their approximate average values, may be classified as follows:

1. Friction between the steam and the metallic surfaces, both stationary and moving,	10%	12%
2. Friction due to eddy currents,	5%	7%
3. Resistance to the rotation of moving parts in the atmosphere of steam, called "windage."	6%	8%
4. Mechanical friction in journal bearings, glands, stuffing boxes, etc.	5%	10%
5. Leakage through clearance spaces, glands, etc.	3%	7%
6. Radiation loss,	4%	8%
7. Residual velocity in exhaust,		

The constant striving to minimize these losses has resulted in improved methods of governing, special devices for cutting, shaping and spacing the turbine blades, exhaustive experimentation relating to the flow of steam through nozzles and orifices, the development of high pressure lubricating systems and high temperature packing, and in the development of remarkably efficient condensing equipment, particularly in units of large capacity.

STEAM TURBINE PERFORMANCE.

A consideration of some particular installations with the results of steam economy tests will indicate the measure of success that has attended the recent development of steam turbine practice.

In 1902, after very careful consideration of the steam turbine problem, the then Commonwealth Electric Co., of Chicago, purchased the first 5,000 kw. machine that was built. Just previous to this, the Westinghouse Company had taken the contract to build a 1,500 kw. unit which was installed in the plant of the Hartford Electric Light Co., of Hartford, Conn. It is worthy to note that the turbine, Unit No. 1 in the Fisk Street Station of the present Commonwealth Edison Co. was the result of the first effort that had ever been made in this country to build a machine of this type larger than 600 kw. The 600 kw. turbine mentioned was a two stage, horizontal Curtis ma chine installed in 1901 in the shops of the General Electric Co., at Schenectady, N. Y. It is a compliment to the engineers and management of the General Electric Co., who built and installed this first larger unit, that they planned and built so well and confidently at that time. We doubt not that, in the light of more recent designs, this first large turbine to be installed in this country fails to nourish the pride of its designer, and yet, all must agree that the undertaking at that time was very meritorious.

The writer has been privileged during the past two years to conduct tests on three of the units in the Fisk Street Station, Commonwealth Edison Co. These units with the approximate dates of installation and their respective kw. ratings are as follows:

Unit No. 1, first operated September, 1902, normal capacity, 5,000 kw.

Unit No. 4, first operated September, 1905, normal capacity, 5,000 kw.

Unit No. 8, first operated December, 1905, normal capacity, 8,000 kw.

A brief summary of the results of these tests is presented in the following table:

OPERATING CONDITIONS.

Comparative Results—Best Performance.

1.	Nominal Rating of machine, kws....	5000	5000	8000
2	Load—Gross output, kws.........	6137	5970	10156
3.	Ditto—per cent normal rating	1.25	1.20	1.25
4.	Water rate—observed kw-hr.......	23.85	16.56	12.94
5.	Ditto—corrected for .... “Contract Conditions”	23.94	16.72	13.07
6.	Water Rate—observed e.h.p.-hr....	17.89	12.42	9.71
7.	Ditto, corrected for .... “Contract Conditions”..........	17.96	12.54	9.80
8.	Initial Pressure, pounds...........	176.6	174.0	176.0
9.	Vacuum observed, inches	28.10	28.0	29.17
10.	Vacuum, 30 in. barometer, inches ..	28.52	28.30	29.50
11.	Superheat—Deg. Fahr.	139.0	184.0	147.0
12.	First stage pressure, lb gage.......	5.66	34.8	46.7
13.	Normal speed, r.p.m.	500	500	750

The accompanying curves, Fig. 12, present the relative steam economies of these three units in a very interesting manner. It will be seen that the scale of the vertical ordinate, representing "Water Rate," is continuous, thus giving a direct comparison of the units, all values of the steam economy having been reduced to the basis

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1. A considerable condenser leakage necessitated a correction in the steam flow of Turbine No. 1.

2. Results of tests of No. 4 taken from Report of Tests of Turbine No. 4, J. C. Thorpe to Mr. F. Sargent, April 24, 1906.

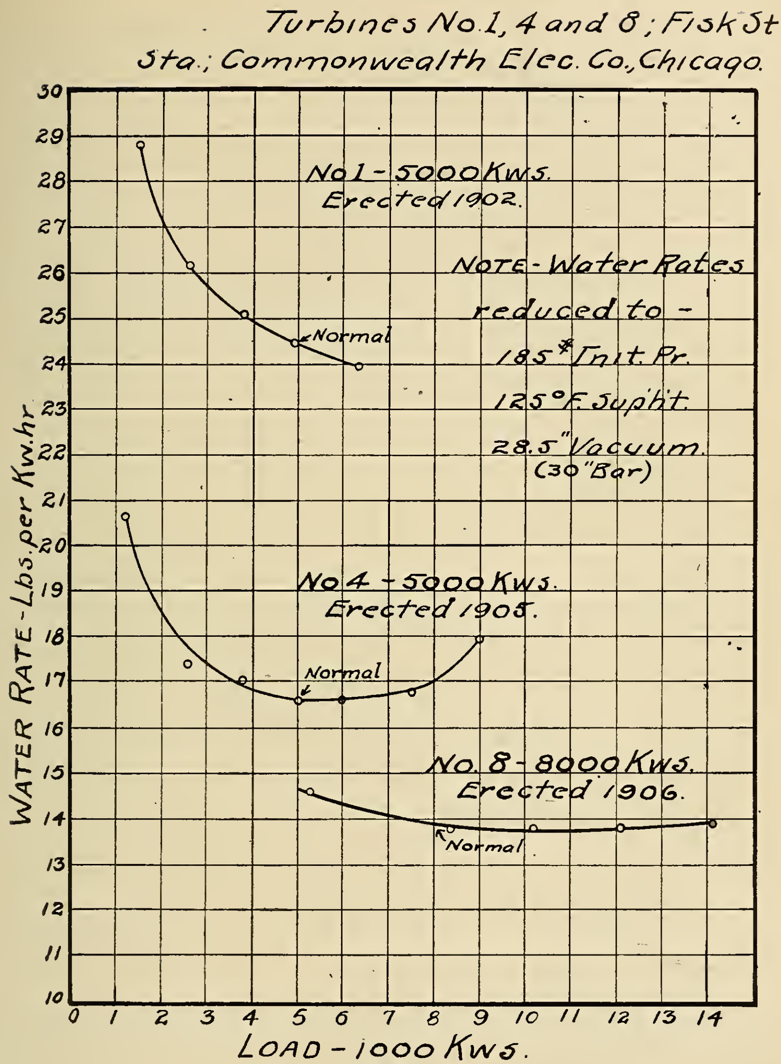

Fig. 12.

indicated. Another notable feature is the flatness of the load curve for Unit No. 8. It is noticeable in No. 4, but less markedly and the tendency to give a wide range of economy with a considerable range of load is hardly perceptible in the first unit. It is difficult to say what the results would have been in the latter case had the load been increased to 75% overload, as in the case of No. 8. These curves serve better than words to illustrate the remarkable development in the design and operation of large turbine units of this type during the past five years.

The curve AA in Fig. 13 represents the steam economy of the 500 kw. horizontal Curtis turbine mentioned above, and curve BB, the economy of a 600 kw. Curtis turbine, erected in the station of the Massachusetts Electric Co. at Newport, R. I. The test was conducted by Mr. George H. Barrus and appears in a bulletin issued by the General Electric Co. The difference in water rate is probably due to the fact that the 500 kw. machine was tested with a service load which fluctuated greatly during each trial; whereas, the test of the 600 kw. machine was a shop test, when more nearly absolute control was had over all of the conditions affecting performance. It might be assumed that the development of four years should result in increased economy. This is not necessarily true, particularly with the smaller units, since the requirements of the service may necessitate mechanical changes whose desirability outweigh the relative importance of an inconsiderable increase in steam economy.

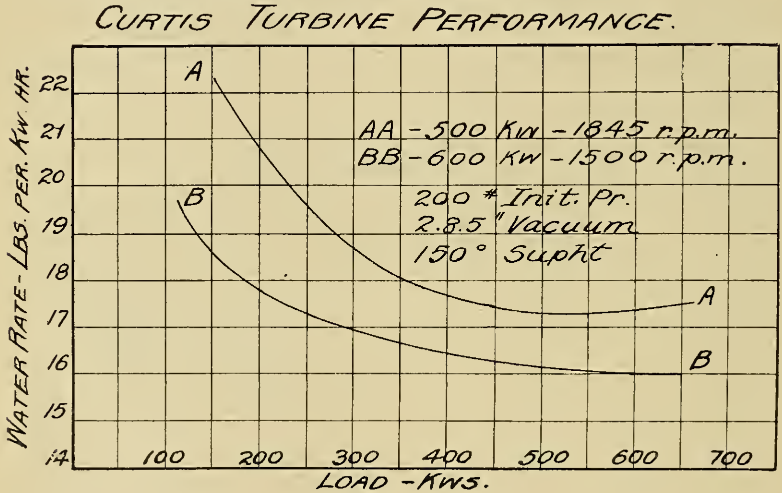

Fig. 13.

In Fig. 14 is presented the load curves of four Curtis turbines of 1,000, 2,250, 5,000 and 8,000 kws. rated normal capacity. In this instance the conditions of operation are not reduced to a common basis, but appear as actually observed. An inspection of the values given will indicate that no considerable change would result if a reduction had been made as in Fig. 13. The curve in Fig. 15 was constructed from Fig. 14, using the steam economy for the points of normal loading and all reduced to a common basis, namely, 185 pounds (gage) initial pressure, 28.5 inches vacuum, (30 inches Bar.) and 150 deg. Fahr. superheat. This curve illustrates the well-known fact that the ratio of the energy losses to normal capacity decreases with the increasing size of units, just as the same ratio varies with the load on a given unit.

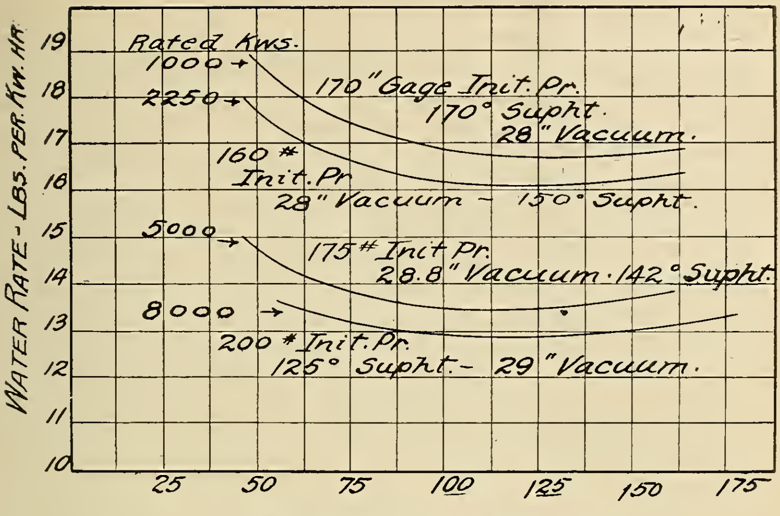

Fig. 14.

Corrections on these curves were based upon the following values, derived from actual tests, when all the conditions of operation, except those under trial, were maintained as nearly constant as precticable:

1 inch vacuum, between 26 inches and 30 inches=5% effect upon water rate.

14 deg. Fahr. superheat=1% effect upon water rate.

10 lbs. boiler pressure between 150 and 185 lbs.=0.5% effect upon water rate.

Difference between 185 and 200 lbs. boiler pressure=neglible.

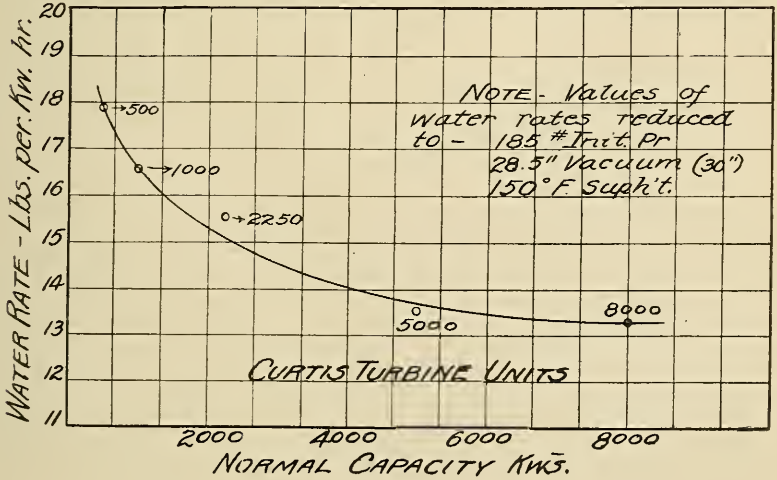

Fig. 15.

In the *Electrical World*, of October 12, 1907, the following corrections for departure from contract conditions during a test of a 7,500 kw. Westinghouse-Parsons turbine in the plant of the New York Edison Company, are recorded:

Pressure—2½ pounds high=corrections, 0.25% in water rate.
Vacuum, 0.69 in. low=correction, 1.84% in water rate.
Superheat, 4.25 deg. low=correction, 0.29% in water rate.

It will be noticed that the influence of the variation in steam pressure is apparently much greater with the Parsons type of machine and the influence of variations in vacua much less, than in the performance of the Curtis type. There is practically no difference in the allowance made for superheat. It appears upon careful consideration that the turbine which governs by virtual throttling, would not be improved to any considerable degree by increases in pressure. Furthermore, the influence of vacua might be expected to be much greater than stated, concluding from experience with other machines.

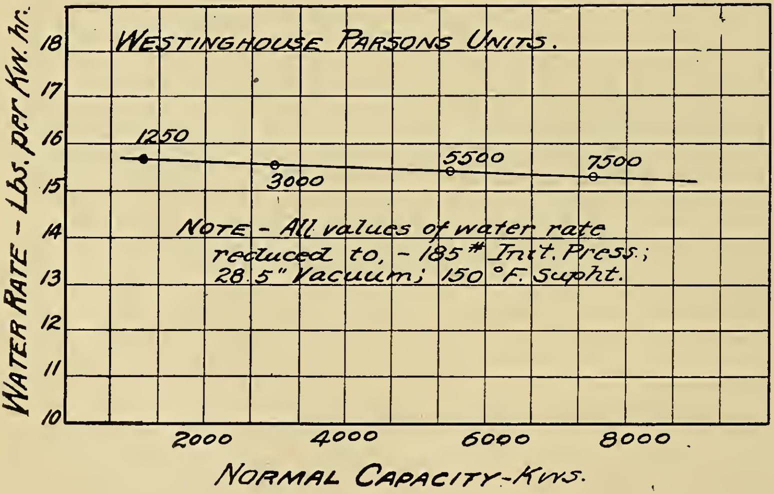

Fig. 16.

In Fig. 16 is presented the relation of water rate of various Westinghouse-Parsons turbine units, plotted upon the same basis as the curve in Fig. 15. The actual load curves from which this curve is obtained appear in Fig. 11. A marked contrast between Fig. 15 and Fig. 16 is immediately noted; a difference in water rate of 3½ lbs. existing between the 1,000 and the 8,000 kw. units of the Curtis pattern, and but 0.5 lb. difference over the same range of capacities in the Westinghouse-Parsons machines. This may be understood after a consideration of the constructive features of the two patterns of turbines. In the Westinghouse-Parsons pattern, the larger units are but magnified copies, if you please, of the smaller sizes, and thus the energy losses bear the same relation to the capacity in any sized unit. On the other hand, the smaller Curtis turbine units are constructively quite different from the larger machines, and the ratio of energy losses to capacity is greater in the smaller sizes.

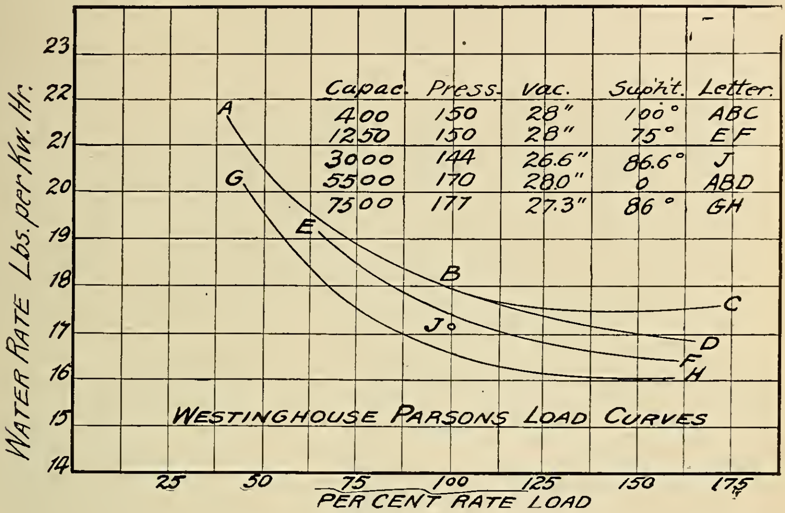

Fig. 17.

As mentioned above, Fig. 17, presents the steam economy of Westinghouse-Parsons units of various rated capacities, under the actual operating conditions. It is significant that the curve of water rate of the 400 kw. unit coincides with the curve of the 5,500 kw. machine up to their normal capacities. Both machines were operating under similar initial and final pressures, but the small unit was supplied with steam superheated 100 deg., whereas the initial steam for the large machine was saturated.

It is exceedingly important, as suggested above, that accurate means be secured for reducing the performance to a common basis for purposes of comparison, whether various types and sizes of units are involved, or the agreement of actual performance with guarantees in contracts is in question. For these purposes "performance curves" should always be determined which will present the variation in economy due to changing conditions of vacua, superheat, pressure, etc. Typical "Performance Curves" are shown in Fig. 18. Most significant of these curves and most worthy of special mention is the "Initial Pressure" curve, which demonstrates the futility, from the standpoint of economy, of increasing the initial pressure much above 140 lbs. gage. Up to this point the inclination of the curve is quite marked, and the advantage of increasing pressures as a means of reducing water rates very apparent. Beyond this point, the curve tends to become more nearly parallel to the pres-

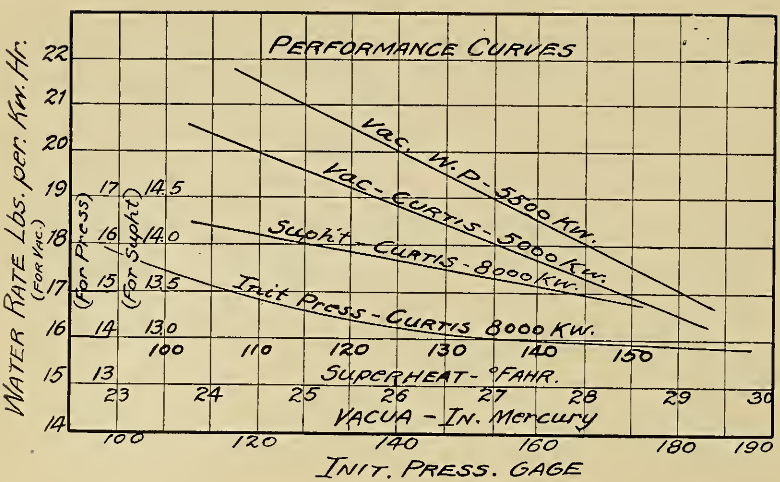

Fig. 18.

sure co-ordinate, indicating an advantage and that a somewhat questionable one, only in gaining capacity. This deduction is in accord with numerous investigations recently conducted, which have resulted in a diminishing of enthusiasm for high initial steam pressures. Some time ago, Professor W. F. M. Goss, Dean of the Engineering College at the University of Illinois, at that time occupying a similar position at Purdue University, presented a paper, which has been widely distributed, based upon investigations of the influence of increasing boiler pressures upon the performance of steam locomotives. The results presented were in direct accord with the preceding discussion. It will be of interest to mention that the government engineers in charge of the steaming tests of the U. S. Geological Survey have also advanced the proposition that lower steam pressures and high degrees of superheat will be found desirable and economical in the operation of steam prime movers. Curves of the same form as the one under discussion were secured in the Mechanical Engineering Laboratory at the University of Illinois from tests of a small turbine unit, of velocity or impulse type.

For some reasons it would be desirable to present performance and load curves for many other turbines that are now playing an important part in the design and operation of power plants. Numerous comparisons, however, have indicated that the curves here presented for the Curtis and Westinghouse-Parsons machines, representing, as they do, the two chief types of turbines, are characteristic both in form and in the absolute values given, of all steam turbines of their respective types.

Before passing from the consideration of steam economy, it will be well to consider examples of the numerous smaller machines that are attracting attention. Among the turbines of this class that have appeared quite recently are the Kerr, Fig. 19, the product of the

Kerr Steam Turbine Company of Wellsville, New York; the Sturtevant, Fig. 20, recently perfected, and now being vigorously supported by the B. F. Sturtevant Company, and the Terry, Fig. 21, built by the Terry Steam Turbine Company of Hartford, Connecticut. These small machines are all of the multi-stage impulse type, the Kerr applying the principle of the Pelton wheel and all of the other mentioned being modifications of the Riedler-Stumpf pattern heretofore discussed.

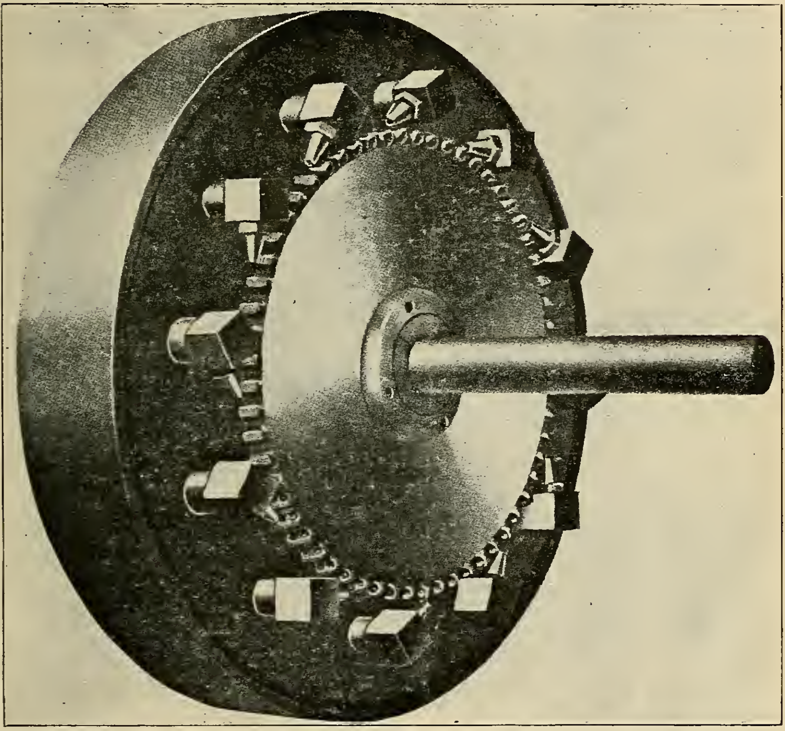

Fig. 19.

These small machines are designed for relatively small capacities of from 15 to 200 b. h. p., and usually for some special application such as driving D. C. electric generators, blowers, centrifugal pumps, etc., and where close regulation is desirable at comparatively high speeds. In general, they are designed to operate non-condensing, with saturated steam, and under such conditions give practically the same steam economy as a well designed high speed reciprocating engine of similar capacity. The accompanying curves, Fig. 22, show the close agreement of the steam economy of a high speed simple reciprocating engine, Curve AB, and a six stage Kerr Turbine, Curve CD, each rated at 60 b.h.p., and operating with an initial steam pressure of 150 lbs. gage, 150 deg. Fahr, superheat, and exhausting to the atmosphere. Curve EF represents the steam economy of the same turbine, using saturated steam. It will be observed that the superiority of the turbine is quite apparent at low loads, due, no doubt, to the reduction of the windage loss occasioned by the decrease in density of the steam at lower stage pressures, a fact that is characteristic of large as well as small units. In this connection it will be interesting to note the graphical representation in Fig. 23, of the relation between Volume, Temperature and Pressures below atmosphere. The rapid increase in specific volume from 4 inches to ¼ inch mercury, absolute pressure, is closely related to the increase in turbine economy, noted in Fig. 10.

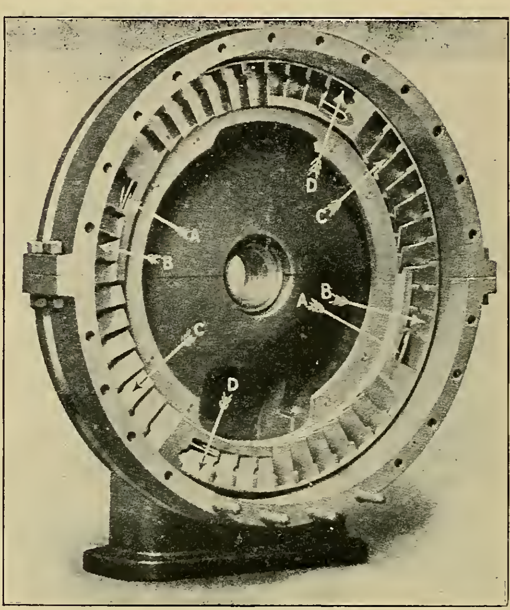

Fig 20.

LOW PRESSURE TURBINES.

A number of plants have been installed more or less recently that have employed low pressure turbines as prime movers, which are operating on the exhaust steam from reciprocating engines in the same station. By this means great economy is effected in the use of the steam, and a saving of practically 65% may be effected by the use of a high-vacua condensing equipment. Practically all of the builders of turbines of large capacity have developed a low pressure turbine and these are playing a prominent part in the design of power plant extensions.

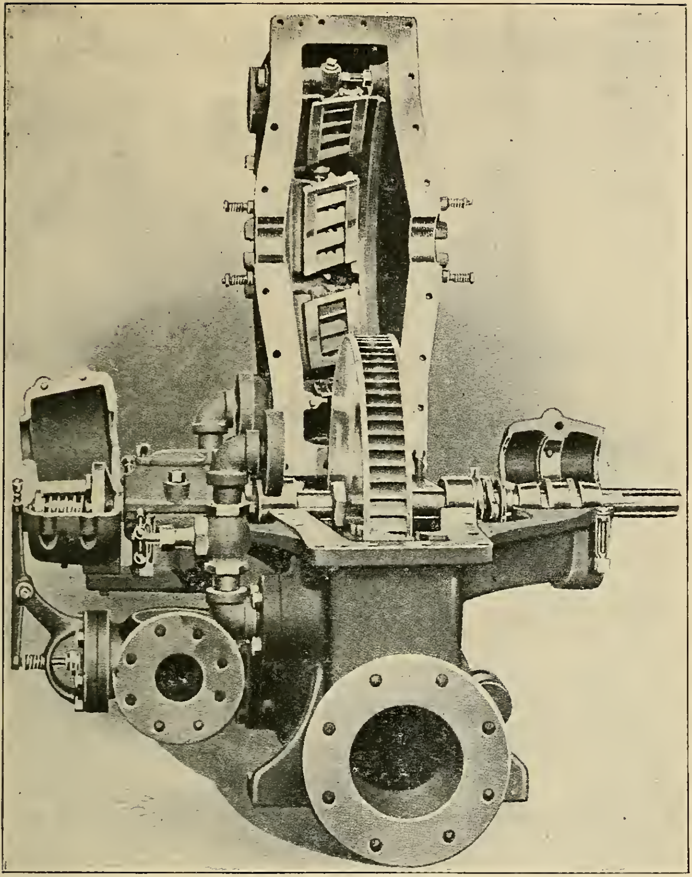

Fig. 21.

In many stations where reciprocating engines are installed they are operating non-condensing on account of the lack of an easily available water supply, and the very considerable expense involved in the installation of cooling towers. In such plants, low pressure turbines may be installed, which, operating between atmospheric initial pressure and 28 inches vacuum, will in many cases practically double the normal capacity of the plant. This, it is apparent, would justify the installation of cooling towers and the most efficient condensing apparatus, and the result would be attained without additional fuel or attendance charges. These turbines may be used to advantage with engines in intermittent service, such as rolling mill engines, where the steam supply is controlled by regenerating apparatus.

Mr. Lionce Battu very ably discussed the principles involved in this problem, in his paper before this society in September, 1904. One of the prominent installations of low pressure turbines been made indicate a water rate well within the guarantee.*

It may be of interest to know that the General Electric Company is now prepared to contract for the installation of Low Pressure Turbine Alternators of capacities (maximum continuous) ranging from 300 to 7000 kilowatts in machines for 60 cycle current with standard voltages; and of capacities from 1200 to 7000 kilowatts in machines for 25 cycle current and standard voltages. Low Pressure Turbine Units for Direct Current are built in sizes from 300 to 2000 kilowatts. The guarantees of steam economy is based upon initial steam of one pound gage pressure, exhausting into a vacuum of 28 inches.

Tests made in the shops of the Westinghouse Co. upon a 1250 kw. low pressure unit have resulted in a water rate of 30 lbs. per b.h.p.hr., this being the equivalent of approximately 38 lbs. per kw.hr.†

HEAT EFFICIENCIES.

The Willans Robinson Company of England, the builders of a popular and efficient type of reciprocating engine, have been experimenting for some years upon improvements in the Parsons type of turbine. Results have been secured that are very satisfactory to

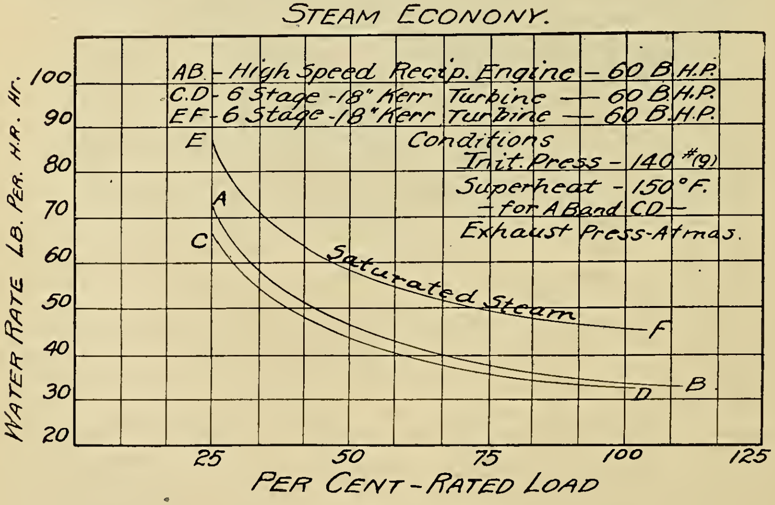

Fig. 22.

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*French's Steam Turbines.

†J. R. Bibbins, Electrical Journal.

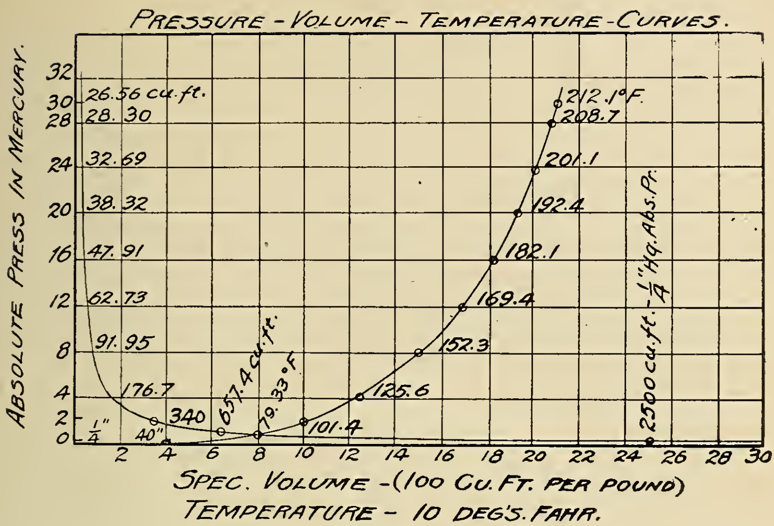


Fig. 23.

the builders, and they are now doing a large turbine business. A contract recently entered into by this company for the construction and erection of a 3,000 kw. unit contained a performance guarantee clause, stipulating a water rate of 12.9 lbs. per kw.-hr. No data was presented with reference to the conditions of operation, but by reference to the curves of Fig. 8, it will be seen that this is equal to the best performance of the 8,000 kw. Curtis turbine.

Now, just what does it mean for a turbine to develop a kilowatt at the switchboard on a steam consumption of 12.9 lbs. per hr.? This is the equivalent of 9.54 lbs. per e.h.p. or with a generator efficiency of 96% it is the equivalent of 9.17 lbs. of steam per b.h.p.hr., further, assuming a mechanical efficiency of 94 per cent for the prime mover, it is the equivalent of 8.62 lbs. per i.h.p.hr., certainly a commendable performance. According to the British Standard as recommended in the report of the committee of the American Society of Mechanical Engineers on Standard Code for Steam Engine Tests, this performance gives a thermal efficiency of 21.4%, closely approaching the best performance of internal combustion engines. The "potential efficiency" of heat engines presents a much more satisfactory basis of comparison than "thermal efficiency" just discussed. This efficiency is defined as the ratio of the ideal to the actual heat change per unit of power. Assuming an absolute pressure of 190 pounds, 150 deg, F. superheat and a vacuum, referred to 30 in. barometer, of 29 in., the above water rate is the equivalent of a potential efficiency of 67.7% based upon energy delivered to the switch board and 75% based upon indicated horse power deduced as explained above. In comparison it is interesting to note that the official trial of a 1000 i.h.p. double-acting, twin-compound Schmidt engine, operating on 155 lbs. initial steam pressure, 25.4 in. vacuum and 330 deg. Fah., superheat, gave a potential efficiency of 83.3%. This represents the best modern practices.

Thus it will be seen that we are fast approaching the limit of economy in the prime mover itself, and future developments must be looked for in the steam generator. Greater economy must be secured in the performance of the boilers. It is significant that practically the same rated boiler capacity was installed for the first 5,000 kw. unit in the Fisk Street Station of the Commonwealth Edison Company of Chicago, as six years later, was installed to operate the 9,000 kw. units. This points to developments in boiler practice as well as to remarkable advances in the large turbo units.

BOILER ECONOMY.

In most plants, the steam driven auxiliaries do not furnish enough exhaust steam to heat the feed water above 120 deg. Fah. The possibility of increasing economy by using *hot* feed water has been taken advantage of in some cases by the installation of economizers, though their ultimate practicability still remains a much discussed question. Other engineers have taken steam from the second or third stage of the turbines to increase the feed water temperature and this without suffering a deleterious effect in economy.

In a recent article before the American Institute of Electrical Engineers, Mr. J. T. Findlay presented a very interesting discussion of experiments with double stoker boilers in the power plant of the Interborough Rapid Transit Company of New York City, made under the general supervision of Mr. H. G. Stott, superintendent of motive power of the Interborough Company. These boilers were 500 h.p. units set with two Roney stokers, one as in the standard setting and the other at the rear at a somewhat lower level. The horizontal baffling was so arranged that the gases from both stokers intermixed and traversed the same passes over the heating surface. This increase in volume of gases, with the resultant higher velocity, effected an increase in capacity of 80% with no appreciable difference in overall efficiency.

This suggests what is very much discussed, namely, the possibility of securing a greater amount of work from our boilers. It leads to the prediction that we are rapidly approaching the point when we will be able to rate water tube boilers on a basis of five square feet of heating surface, per h.p. instead of ten, as now used. Experiments such as are now being made, of which the one cited is a good example, foreshadow the design and operation of larger boiler units, the reconsideration of generally accepted theories regarding heat transmission through boiler heating surface, and the re-design of boiler settings that have been standard for years. There must be a constant striving for better evaporative performance;—for a decrease in the radiation and unaccounted for losses in boiler practice, if this factor in power plant development is to keep pace with the modern prime movers.

RATING OF STEAM TURBINES.

An inspection of the curves of Fig. 14 and Fig. 17 suggests a very significant fact pertaining to the rating of steam turbines. The maximum steam economy is obtained at loads varying from 115 to 130% of the rated capacity of the units, and no considerable increase in water rate occurs at 150% of the normal rating. This is in direct contrast to the conditions which obtain in reciprocating engine practice, where increasing the load above the normal rating or point of maximum economy, brings about a marked increase in the water rate. The reciprocating units are designed to sustain a certain overload for a period of time, usually 50% for two hours, but it is obvious that this maximum capacity should not form the basis for normal rating. In the light of these facts, a change is being effected in the system of rating turbines, and it will not be long until such rating will be based upon the continuous maximum operating capacity instead of upon a normal load basis of the turbines, and generators will be installed capable of such continuous operation. It will be seen that this will not present a radical departure from the practice which now obtains with reference to some prime movers, such as gas engines or water turbines, where the best performance occurs at points of maximum capacity, and where guarantees of performance seldom contemplate any considerable overload capacity.

The General Electric Co. are taking a prominent part in effecting the changes in the rating system just discussed. The guarantees of this company will contemplate continuous operation at maximum capacity. It seems reasonable to suppose that this method of rating will soon govern the practice of all builders of turbines, particularly of units of large capacity.

VENTILITION OF GENERATORS.

The operation of turbo-alternators at their maximum capacity for periods of considerable length has caused some little concern regarding the ventilation of the generators, on account of the unusual increase in temperature of the windings, in a number of instances. In the vertical machines where the generator is placed upon a low stool directly above the turbine and separated from it by a short distance, various systems have been used with varying degrees of success until now a special duct is sometimes provided for the introduction of cool air, the flow being superinduced by the draft of the rotating element. It can be seen that the problem presented is more complex in this instance than in the case of the horizontal machine. In the latter type of turbine, the closed type of generator, Fig. 24,

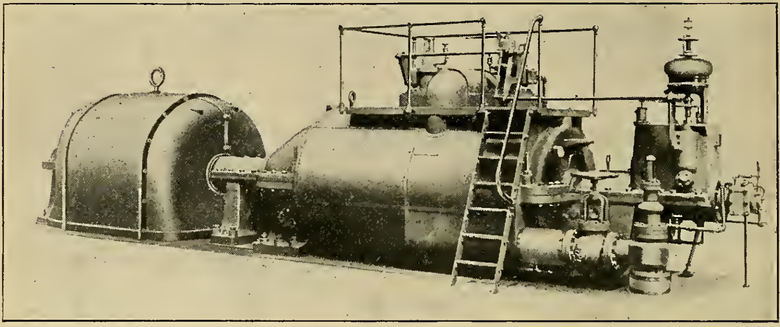


Fig. 24.

has become quite popular. This form of construction permits the application of a very effectual closed forced or induced draft system with the blower on the generator. In some cases this is supplemented by an independently driven blower to reduce the heating effect during periods when unavoidably heavy overloads occur. This careful attention to generator ventilation insures greater safety and makes possible the attainment of an overload margin hitherto quite impracticable and unsafe.

CONCLUSION.

A number of matters pertaining to recent steam turbine development have been discussed. There are many others that might be profitably considered at this time, such as improvements and inventions pertaining to system of governing, methods adopted for securing blades to the stationary and rotary elements to prevent dangerous stripping, new devices for balancing end thrust in horizontal machines, the design and operation of large condensing units, etc., etc. All of these are of importance and constitute the distinguishing features in particular machines, but lack of space prevents a discussion of them at this time.

In conclusion it should not be said or inferred that the steam turbine is supplanting the steam engine in the broad field of the latter's usefulness, nor that the days of the "old reliable" are numbered. Certain it is, however, that for electric generation for all purposes, particularly in large units, the steam turbine of the past decade has proven its superiority.

The importance of the subject in hand should impress every engineer and it is urged that a continuous effort be made by our society to keep pace with the rapid progress of the steam turbine as a prime mover. It is hoped that the discussion of this paper will develop interesting and valuable information for all.

STEAM TURBINE DEVELOPMENT.

Chronological Table.

120 B. C.	First Reaction Turbine, Aeolpile; Hero of Alexandria.
1629 A. D.	First Impulse Turbine. Grovannia Branca of Rome.
1629	First Attempt to Utilize Steam Turbine at Moderate Speeds. Real and Pichon, France.
1831	First United States' Patent. 10 H. P. Reaction Turbine, Wm. Avery, Buffalo, N. Y.
1838	Experiments with Expanding Nozzles in "Avery" Turbine. Leroy.
1842	Compound Principle Applied. Attempt to Design Reversing Turbine. Pilbrow.
1848	Compound Reaction Turbine, the Forerunner of the Parsons Type. First to Properly Consider the Effect of Increasing Volumes with Decreasing Pressures. Wilson.
1853	Speed Reduction by Gears. Cut Off Ring for Governing. Delonchant.
1858	Compound Impulse Turbines, Suggesting the Modern Curtis Machine. John and Ezra Hartman.
1863	Return Pipes and Double Set of Blades to Cause Double Action of Steam on the Same Wheel, Hoehl, Brakell and Gunther.
1877	Compound Impulse Turbine Employing Gradually Increasing Steam Areas. Forerunner of Hamilton-Holzwarth Machine. Moorhouse.
1879	Compound Radial Flow Turbine. Cutler.
1881	Compound Impulse Turbine with One Wheel. Semi-Circular Buckets. Imray.
1883	Speed Reduction by Friction Gearing in Turbine of "Avery" Principle. This was the First Patent of the Famous De Laval.
1884	Radial Inward Flow Turbine. Speed Reduction by Spur Gears and Pinion. Babbitt.
1885	Balanced End Thrust by Dividing Machine into Two Separate Sections. Hon. C. A. Parsons.
1888	Pressure Stage Feature Invented. Parsons.
1893	Radial Outward Flow Type. A Popular Machine of the Early Day. Dow.
1894	Expanding Nozzle Patented. De Laval.
1894	Patent Covering Use of Expanding Nozzles with Compound Impulse Turbines. Precedes Curtis Patents by Two Years. Maison Breguet.
1894	Beginning of Pelton Wheel Type of Steam Turbines. McElroy.
1894	Single Wheel with Pelton Buckets, Employing Special Reversing Mechanism. Rateau.
1895	Design of "puff" Governor for Parsons Type of Construction. Parsons.
1895	Applies Expanding Nozzles to Compound Impulse Turbine. Another Forerunner of the Curtis Machine. Sebastian Ferranti.
1896	Group of Patents Secured by C. G. Curtis, now Controlled by General Electric Company. Various Points Covering the Application of Expanding Nozzles to Multi-Stage Impulse Turbines. Special Curtis Governor.
1897	Effort to Mix Water with Steam to Reduce Velocity. Fault Lies in Reduced Kinetic Energy. Bollman.

1898	Special Modification of Pelton Wheel Buckets. Nickel Steel Square Section Expanding Nozzles. Nickel Steel Wheel Discs. Stumpf, Berlin.
1900	Radial Arms Machined in the Shape of Pelton Buckets for Considerable Distance from Circumference. Zoelly.
1903	Modified Form of Zoelly Turbine. Cup Shaped Buckets. Wheel and Speed Reducing Gears Rotate in Steam Chamber to Reduce Noise. Increase Durability and abolish Packing Glands. Richards.
1904	Cup Shaped Pelton Wheel Buckets. Throttling Governor. Designed to Run Non-Condensing with Saturated Steam. Kerr.
1905	Warren Steam Turbine. Composite Type Providing Expansion only in fixed Blades. Drum similar to Parsons Type. 100 to 3,000 Kw. Units. Warren Electric Manufacturing Company. Mr. E. C. Crocker.
1905	Hamilton Holzwarth. Modifications of Riedler-Stumpf. Composite Type. Throttling Governor with One Main Valve. High and Low Pressure Sections for Large Units.

DISCUSSION.

President Loweth: What is the relative durability of the steam turbine as compared with the reciprocating engine? Has the steam turbine been in service long enough to determine that?

Prof. Thorpe: I cannot answer that question positively, Mr. President. Turbines have been installed for years, it is true, and yet the changes have been so marked throughout recent years it would be difficult to base any estimate on anything except maintenance charges and data of that sort, which are not always available. The simplicity and construction would have some bearing upon that, and I see no reason why the steam turbine should not be even more durable than the reciprocating engine.

Mr. W. L. Abbott, M.W.S.E.: I think this Society is fortunate in having this matter presented by one who not only is thoroughly familiar with the theory of the turbine, as a professor of Mechanical Engineering, but also is familiar with it as a practical working engineer.

At the beginning of the paper we were shown what the earliest steam prime movers were—steam turbines—and for several centuries the entire development of steam power was in that line, and had it not been for the impetus given to reciprocating engines by the work of Watt, and others of his time, the turbine would very likely have been commercially developed a century ago, and would have been the real (steam) prime mover, but on account of the work done by those engineers, the reciprocating engine was developed to a higher degree than the steam turbine, and therefore held the field. Work on steam turbines was, however, continued by various inventors, and I think a careful study of the history of the subject would reveal the fact that at any time during the past 125 years the steam turbine has not been more than two decades behind the reciprocating engine, in its development. In other words, had the development of the reciprocating engine been delayed, say, twenty years at any time, or had there been such an impetus to the steam turbine as we had given to the reciprocating engine, the turbine would have been the commercial prime mover long ago.

The speaker shows a diagram containing three curves, representing the improvement in the economy of the Curtis turbine within a period of, say, five years. The water rate on the first was about 24 lbs.; the water rate on the last one is but a little more than half that.

In the latter part of this paper some figures are given, showing that the turbine now is developed to within 25 per cent. of the ultimate possibility. That is, we now realize within 25 per cent. of the highest economy which will ever be possible with the steam turbine or any other steam motor. When we consider that within the past five years, we may say, the water rate has been cut in two and consider what little margin remains to work on, we see that the steam turbine, as far as efficiency is concerned, is very near the end of its road. There are possibilities remaining yet, of course for improvement in its general design, greater reliability perhaps, or cheaper construction, etc. There is also a possibility of improving boiler economy by perhaps one-third, but when we approach the not distant limit of economy of the boiler and of the turbine we shall be obliged, as the speaker intimated, to turn to some other prime mover to obtain still higher economies.

The development of water power is now demanding the attention of engineers and capitalists, but to me it seems that those who are putting their money in these ventures do not fully realize the changed conditions brought about by the development of the steam turbine. A steam power house can now be built at a cost far below the development cost of most any water power, and the fixed charges on the steam turbine plant, if located near the place where its power is to be used, will be far below that of a water power with a long transmission line. The power of Niagara Falls, or any other great waterfall, is, of course, a potential source of wealth, but its value I consider has been greatly diminished relatively of recent years by the development of the steam turbine and the general development of large power houses, which permit the generation of power from coal with a lower initial investment, and with very little higher operating costs.

President Loweth: The steam turbine seems peculiarly adapted for the generation of electrical energy and for marine purposes; is it being used to any great extent for other than these purposes?

Professor Thorpe: There are a number of special applications of the steam turbine, and perhaps the most prominent one is that in connection with centrifugal pumping machinery. The recent development in design and operation of centrifugal pumps presents a promising field for the steam turbine. Most of the turbines of smaller capacity have also been used in blower work.

Prof. A. W. Moseley, M.W.S.E.: I always rather assume that the over load capacity is limited largely by the electrical rather than the steam part of the unit, particularly with turbo-generators. I would ask if that is not true, or whether it is more a matter of electrical design to make the generator of sufficient capacity?

Prof. Thorpe: I have in mind instances where the opposite conditions have been obtained in machines of very similar construction. I believe that the generators will always be designed, as far as possible, to take care of the overload capacity of the turbine. For example, if the turbine's maximum capacity is 14,000 k.w., the guaranteed maximum operating capacity of the generator will also be 14,000 k.w.

Mr. C. G. Y. King: I was recently in a small town where I saw a turbine that had been opened up for investigation and some slight repairs, and in which there was a heavy deposit of mud. This turbine was operated by what was considered to be pure steam. The circulating water was taken from the river and was passed, through the surface condensers; the steam was supplied by one or two boilers through a superheater. What I would ask is if anyone knows of a similar case, and what the condition of the superheater was; how much mud there was in it, and what effect the mud had on the buckets of the turbine.

Mr. A. Bement, M.W.S.E.: In answer to Mr. King's inquiry, I will say that it is probable that mud was carried into the superheater by water which went out of the boiler with the steam, or in other words, by a condition of priming. This is entirely reasonable, as we know that it occurs where superheaters are not employed, due to improper design in boiler drums which allow water to be carried with the steam, and such water will be accompanied by mud that is present as a scum on the surface.

Prof. Thorpe: It is comparatively easy to tell what would happen to the turbine if it were continually operated on steam and mud. Most of us have seen pictures of corrosion due to wet steam, and if there are any solid particles it would only aggravate that condition until the turbine would finally become of no use at all.

President Loweth: What is the relative cost per H.P. of large and small sizes of steam turbines as compared with reciprocating engines of approximately equal efficiency. Of course the answer to this question must necessarily be but a roughly approximate one.

Prof. Thorpe: In order to arrive at a satisfactory estimate on that particular subject, we ought to agree to take the prime mover and generator together as a direct-connected unit. Ordinarily we think of the medium size of reciprocating engine and generator as costing about $35.00 to $40.00 per k. w. In any event, with machines of similar capacity I believe the first cost of the turbine driven unit would be slightly less than for the reciprocating engine.

Mr. Wm. B. Jackson, M.W.S.E.: In his remarks, Mr. Abbott spoke of the possibility of having come pretty well toward the limit of efficiency in the matter of steam turbines. In this, however, I am hardly willing to agree, because in the old days, when we were getting 88 per cent., we thought we were very nearly the limit and then ran that up 10 per cent. better. We also have the saving that is just as active and important in the question of cost which the President has just brought up, and there is no reason to suppose that at the present time we have even approached the limit of reduction in the cost and manufacture of the steam turbine generating unit. In that same regard it seems worth while to emphasize the fact that, although the efficiency element may be very different as regards the steam turbines and internal combustion engines, yet there again we have that element of cost, which is a very important factor as determining the value of machinery.

Prof. Thorpe: One instance of a large machine showed rather a decided inclination of the water rate curve away from the horizontal axis, as represented in the chart tonight. That is the condition—it is practically the same except not quite so aggravated as obtains in the reciprocating engine.

Mr. P. Junkersfeld, M.W.S.E.: Mr. Jackson called attention to the possibility of further reduction in cost of the steam turbine station. That reduction can be made in two ways. Of course there are some further possibilities in reduction of first cost of the unit and in increasing its efficiency. In neither of these elements, however, is the field very wide. The largest possibility is in reduction of cost of other elements that go to make up the station. It is the incidental saving, rather than the direct, that offers by far the greatest possibilities.

Prof. Thorpe states in his paper that a contract was recently entered into by the Willans-Robinson Co. of England, for the construction and erection of a 3,000 kw. unit which contained a performance guarantee clause, stipulating a water rate of 12.9 lbs. per kw. hr. Two years ago the standard guarantee of the A. E. G. Co., of Berlin, was 13.2 lbs. per kw. hr., so that, in the last two years they also have come to the top of the curve and have not made much further headway,—the guarantee being very little better than that of two years ago. It is with pride that we note that one of the turbines which has made particularly good headway, is of American invention, most of the other patents being controlled abroad.

Referring to the question in regard to the generator: There have been some new experiences within the last two years, largely due to the fact that the generator design for turbines was necessarily patterned after water-wheel practice. After the large turbines were run with generators, it was found that an entirely different condition existed. The large amount of energy given off in such a comparatively small mass meant that the maximum temperature would be reached in a short time—less than half an hour. The result has been re-rating of the turbines and building the generator big enough so it can reach its maximum temperature in that space of time.

Mr. A. Bement, M.W.S.E.: Professor Thorpe's paper is of the very greatest value and to my mind the best contribution I have read on the subject of the turbine. Its development is very clearly outlined, enabling one to readily see that the machine has arrived at its present stage of growth by a natural process. To me, the most important feature of the paper as indicating the enormous improvement that has taken place, is the diagram, Fig. 12, the water rate curves therein speaking for themselves, and in a graphic manner demonstrating the advancement which has occurred within the last five years. When it is considered that the steam turbine as a commercial machine has an existence of but a few years, it is decidedly significant that such great improvement should be effected in so short a time, and this appears favorable to early realization of additional development.

This leads to the matter of desirable initial steam temperature or degree of superheat, and I would like to ask Professor Thorpe what degree of superheat he considers most beneficial, and if he has any reason for limiting it as long as it is not of sufficiently high temperature to cause damage to metal parts of the apparatus.

In reference to the tests by Dr. Goss with high pressure steam in locomotives, I do not think the reasonings would apply to turbine conditions, because if I understand rightly, the difficulties with the locomotive were those of lubrication, leakage through joints, etc., features which do not have an application in turbine practice. The experience of the United States Geological Survey probably has not been sufficient to establish an authoritative opinion relative to the matter of desirable steam pressure. This idea originated, I think, while Mr. Ray was in the employ of the Chicago Edison Co. At that time it was my observation to him, that the relatively greater economy of the steam turbine at low as compared to high pressures, suggested the feasibility of carrying less steam pressure to insure a lower temperature of the contents of the boiler, so that heat absorption would be more complete with consequent higher efficiency in steam generation, and the question was, whether this would be sufficient to overcome the loss in the turbine due to the reduced pressure, and this line of inquiry suggested the possibility of very high superheat in connection with it, but I am not aware that the Geological Survey has given the matter further consideration. It is a fact, however, that European experience (that of Schmidt, for example, who obtained very high efficiencies with reciprocating engines), was with steam at a high degree of superheat, but with prevailing types of boilers high superheat requires the superheater to be located close to the fire rather than near the chimney, so that the hot gases may act upon it after having passed over only a small portion of the boiler surface.

I think it unfortunate that as a general thing there has been so little discussion of the factors which influence efficiency with turbines. After all, when the matter is summed up, it would appear there are only three possible sources of loss, to-wit:—

a. Heat in the exhaust,
b. Radiation from the exterior of the machine,
c. Velocity in the exhaust,

and strictly speaking, I do not think that items 1, 2, 3, 4 and 5 given as losses on page 549 of the paper, should be so considered for the following reasons:—

Friction between steam and the metallic surfaces must result in the generation of heat. This heat is either returned to the steam flowing through the machine or else radiated away from the exterior of the casing, but inasmuch, however, as it cannot raise the temperature of the turbine casing from that due to normal condition, it could not contribute to the radiation loss, therefore the heat would find its way into the steam to be transferred into work, or else would escape with the exhaust. The same reasoning applies to friction due to eddy currents, likewise the resistance of the steam to rotation known as windage. The mechanical friction of journals, etc., which are located in the steam spaces, would contribute in a measure to heating of steam. The figure of 5 per cent, however, is so high that it raises the question whether the friction of the entire machine, generation included, is not charged against the turbine. At all events, for a study of the heat efficiency of the turbine, it would be desirable to eliminate the consideration of what is strictly mechanical friction occurring outside of the steam chambers of the machine. According to the foregoing, the improvement in the turbine must certainly have occurred through a reduction in the amount of heat carried away in the exhaust steam. The theory of the turbine demands that it be more efficient than a reciprocating engine, and if I am not mistaken, it was prophesied that such result would be obtaied, and early experience must have been more or less of a surprise. In view of the fact, however, that so great improvement has been accomplished in the last few years, would indicate that if still more energy of the steam can be transformed into work through perfection in mechanical design and construction, there will be a demand for a very high degree of superheat.

In steam engine practice the term leakage is quite a significant one. Somehow it has not been considered so important a matter with reference to the turbine, but I think that leakage, or in other words, a condition which allows steam to blow through the machine into the condenser without doing work, should have more recognition than it has thus far received.

Relative to the improvement in the first unit of 5000 kw. capacity and the later ones of 9000, I feel that the gain has been very largely in the turbine rather than in the boilers, as the following tends to show:

Boiler, square feet	5200	5200
Superheater, square feet	960	960
Grate surface in square feet	75	90
Height of chimney, feet	200	250

which I think shows that the increase in capacity from the boilers is due to a larger grate and a higher chimney, or in other words, increased facilities for burning coal; while on the other hand, the comparison between the turbines is as follows:

Rated capacity, kw	5000	9000
Water rate per kw., pounds	23.85	12.94
Pounds of steam required per hour, per turbine	119,250	116,460
Ratio between steam quantities required	1.024	1.00

Thus it will be observed that the demand for steam by a 9000 kw. turbine is 2.4 per cent less than that required to develop 5000 kw. with the old machine, eight boilers, of course, being employed in both cases to supply one turbine.

The matter of ventilation of generators is one which interests me very much, and I am glad to see that Professor Thorpe has said something about it. In this connection I would like to ask him what the prospects are for closing up generators so that noise may be eliminated, and, effecting ventilation by other than natural means. To me the greatest objection to turbines is the noise made, which with the early example of the Westighouse-Parsons before a jacket was applied, was very serious and dangerous, as it was impossible to know through sense of hearing what was going on in the turbine room. I do not believe the matter has been taken up seriously with the realization of what the requirements demand. The magnitude of the problem may be apprehended if we assume a station of ten turbines each of 9000 kw. capacity, with a 98 per cent efficiency. This would mean a liberation of 6,141,600 heat units per hour equal to burning of 585 pounds of coal in the same length of time, sufficient to raise 5,174,136 cu. ft, of air per hour 5 degrees in temperature. The present tendency is, of course, toward a much larger and more expensive generator, having high efficiency and consequently wasting less energy in the form of heat, which simplifies the problem.

Prof. Thorpe: With respect to the two questions brought up by Mr. Bement, his inference is true that the tests recorded in the paper on superheat engines were made with a high degree of superheat—600 deg. Fah. It is characteristic of foreign practice to use those high degrees. The average in this country I think might be said to be 125 deg. Fah., or perhaps a little less. The possibility in the use of higher superheat is very promising, it seems to me, and I believe most of us are looking forward to developments along that line. We were limited in the past by mechanical difficulties rather than a more or less complete understanding of the steam action itself.

With reference to the ventilation of generators, I feel hardly qualified to speak on that subject. I think Mr. Junkersfeld can present more valuable data on that subject than I can, owing to his intimate knowledge of electrical design and his relation to that practice. No doubt we are all familiar with the efforts being made by generator designers to lessen the noise and give better ventilation. In one of the pictures shown was a Westinghouse unit completely inclosed.

This feature is embodied in the late designs of turbo-generators by all of the prominent builders. It makes possible the use of mechanical ventilating systems, and reduces the noise to a minimum.

Mr. Junkersfeld: With reference to the matter of ventilation and lessening the noise of generators, this is something that all the maufacturers are still working on. It is easy enough to close a generator, but not so easy to keep it closed and get results. I think that after another two years have gone by, some of the problems that are now puzzling us will be solved. There are a good many installations under way which will be quite different from anything thus far in service, and we shall have to wait a little time before we can judge of their effectiveness.

President Loweth: Our Past President, Mr. Abbott, suggests that perhaps there are some engineers who have not kept pace with the improvements being made in steam turbines, and the speaker, speaking for himself, knows this to be true. In this age of rapid evolution in engineering matters, there is a great deal more going on than one mind can well keep in touch with. Great credit is due to those engineers who have so rapidly brought the steam turbine to such a high degree of efficiency, and especially to those who have had the courage of their convictions, both to buy and to sell such large units as have been lately successfully installed, and it is gratifying that their success has been so marked.

Mr. C. V. Kerr (by letter): I am glad to see Prof. Thorpe take the stand he does on comparing the performance of heat engines on the potential efficiency. We have for a long time rated water wheels on the ratio of work developed to the potential energy of the water fall. As steam expands adiabatically a certain amount of heat is made available for conversion into work and there is no chance whatever for the engine to develop more than this theoretical quantity. In the gas engine also there is an available heat represented by the fuel value above the normal level of atmospheric pressure and 32 degrees F. This potential efficiency basis, therefore, gives a just comparison of the performance of different classes of prime movers under the conditions in which they are compelled to operate. On this basis steam turbines and steam engines have developed from 70 to 80% by record tests of the theoretical amount of power. Water wheels have developed 80 to 85%. The gas engine, however, developing a b.h.p. on 12 cu. ft. of natural gas with a heating power of 900 B.t.u. per cu. ft. has a potential efficiency of only 23.5%. It is, of course, true that the actual fuel consumption of the gas engine per b.h.p. is less than that of the best performance of the steam turbine or steam engine at present. As compared with the steam engine, however, the gas engine shows a far lower potential efficiency. The steam boiler will put into the steam from 70 to 75% of the fuel value of the coal burned. The combined efficiency of the best boilers and the best steam turbines will be close to 50% efficiency on the basis of available heat due to expansion of the steam.

There is a great field for the steam turbine driven auxiliaries in power plants. As stated, in most plants the auxiliaries do not furnish enough exhaust steam to fully heat the feed water. The exhaust steam from the steam turbine is entirely free from oil so that no trouble or danger comes from this source to the boilers. With the installation of turbine driven boiler feed pumps, circulating pumps, hot well pumps, exciters, blowers for forced draft and the like, the demand for exhaust steam to heat the feed water will be met with a supply of exhaust as clean as when it comes from the boilers. If my information is correct trouble has come in economizer installations due to sweating of the tubes when cold feed water is passed thru them. If the exhaust steam from the auxiliaries is first used to heat the feed water and it is afterwards passed thru the economizer tubes such trouble with sweating will be largely avoided and the further use of chimney gases will lead to the highest possible efficiency of the plant.

In the case of the small steam turbine used for driving blowers, centrifugal pumps, generators and other high speed machinery, it is almost absurd to take any other rating than that based on the continuous maximum operating capacity. If a blower requires 30 h.p. what is the use of putting a turbine on it that is rated at 25 h.p. and giving it an artificial 20% overload capacity to meet the demands of the blower? The same thing is true of the centrifugal pump, as well as of driving generators. It is the custom of my Company to put into the turbine the maximum h.p. that is to be required of it under operating conditions no matter what the driven machine may be and to rate the turbine accordingly. I believe this is the right way to meet the question of rating and that this practice will finally prevail.

Prof. G. A. Goodenough (by letter): In the question brought up by Mr. A. Bement regarding the losses in the steam turbine, we must take issue with Mr. Bement's statement that Items 1, 2, 3, 4 and 5 of page 549, should not be considered as losses. Take the case of Item 3, Resistance to the Rotation of Moving Parts in Atmosphere of Steam, or Windage. Here work is converted into heat, and as Mr. Bement states, the heat is returned to the steam in subsequent stages. To be sure, there is no loss of energy; that is, our law of conservation of energy is not violated. There is, however, a loss of availability; that is, the heat that has been produced by the work can in no way in the subsequent stages be made to give back the work that was expended in generating it. In fact, it can be made to give back only a very small fraction of that work.

For example, suppose that in a given stage 10,000 foot-pounds of work are expended in windage. This means that the equivalent of 10,000 foot-pounds is produced as heat at some definite temperature. Now if the thermodynamic efficiency of the turbine reaches the high value of 20%, then not more than 20% of the 10,000 foot-pounds can be recovered as work; the remaining 80% must inevitably be lost.

The same statements may be made of the other items, Friction between the Steam and Blades, Friction Due to Eddy Currents, etc. These losses are good examples of the real meaning of the second law of thermo-dynamics, or in a broad sense, the law of degradation of energy. All of these frictional processes are irreversible and give rise to a certain loss of availability.

CLOSURE.

Prof. Thorpe: In closing the discussion, a few points mentioned heretofore may be considered very briefly.

First, in reference to cost of turbines it may be said that the great factor in economy is noted in decreased floor space required and in the great lessening of foundations. The vertical turbines occupy about two-fifths and horizontal turbines about three-fifths of the space of reciprocating engines, and are so well balanced that units of large capacity have been placed upon the second floor of power plant buildings. Where real estate values are high, this feature is of significant importance when referred to the plant initial cost.

Second, in reference to the matter of high steam pressures discussed by Mr. Bement, it seems to the writer that Dr. Goss' work at Purdue resulted in most conclusive evidence that the value of high steam pressures has been overestimated. The fact that this evidence was collected in locomotive service need not present a questionable condition. That the locomotive, though operated under the most trying conditions, is a very economical power plant is not to be denied.

In further reference to Mr. Bement's discussion, his remarks on energy losses in the turbine are very interesting and timely, though if a general comprehensive classification of these losses were attempted, it might well consist of two items; first, Thermal Losses; and second, Mechanical Losses. In the discussion of this subject, the writer attempted only to present the various conditions affecting the total energy loss. Professor Goodenough has explained very clearly that there must be an ultimate loss due to the conditions named, based on the theory of "The Degradation of Energy," which affects the operation of all prime movers.

Third, in reference to Mr. Kerr's discussion of the coal rate of the turbine as compared with the Gas Engine which boasts of its brake horse power per pound of coal, it may be said that if the same grade of coal were used under the boilers, the steam turbine, too, would develop an electrical horse power on one pound of coal.

In closing, the author wishes to thank those who have contributed to the discussion, and to acknowledge the very considerable courtesy of Mr. French, for permission to present some material from his splendid book on "Steam Turbines," and of the various turbine builders whose co-operation aided very materially in the presentation of this paper.

THE APPLICATION OF THE STORAGE BATTERY TO LIGHTING, POWER AND RAILWAY SERVICE.

Read before the Electrical Section, Mar. 15, 1907.

By J. M. S. Waring.

In this paper I have divided batteries for lighting, power and railway service into two general classes under the headings, (A) batteries for railway and power service; (B), batteries for lighting service, and have subdivided each of these classes under two sub-headings. I have then shown the functions of the storage battery for the classes of service falling under these sub-headings. These divisions and subdivisions are shown by a diagram on the following page:

For the purpose of this discussion, I have divided the paper into two parts, the first part treating of the means of controlling the charge and discharge of batteries; the second part treating of the results accomplished by the batteries in their various applications to lighting, power and railway service.

Part First.

In order to properly comprehend the method of regulating battery charge and discharge, it is necessary to be familiar, first with the general characteristics of a storage cell, and second, to have a thorough conception of the method of maintaining some predetermined charge or discharge of the cell for some fixed period of time.

Sketch 4 illustrates in a general way the discharge curves of a cell at various rates, and also a charging curve at the normal or eight hour rate. In discharging a cell at any rate, the voltage at the beginning will drop rapidly; then the drop in voltage will be comparatively slight over a long period until near the end of the discharge when it will again drop rapidly. What is known as the limiting discharge voltage of a cell at any rate is a point just over the break in the curve. If the cell were allowed to dicharge beyond this point, at the same constant rate, its voltage in a very short time would drop to zero. During the charge of the battery at any rate, the voltage will rise rapidly at first, then less rapidly until near the end of charge, when it will again rise rapidly to a point generally known as the maximum charging voltage. If the charge is continued beyond this point, the voltage will remain practically constant. As soon as the flat part of the curve is reached, the cell is completely charged, and the further passage of current will give practically no additional capacity.

- (A) Railway & Power Service
  - (1) P.H. or S.S. Battery
    - Current Regulation
    - Peak Work.
    - Current Reg. & Peak Work.
    - Emergency Reserve.
  - (2) Line Battery
    - Current Regulation.
    - Peak Work.
    - Current Reg. & Peak Work.
    - Improving Line Voltage, Copper Saving, Offsetting Rotary S.S.
    - Emergency Reserve.
- (B) Lighting Service
  - (1) Central or S.S. Battery
    - Peak Work.
    - Emergency Reserve.
    - Voltage Regulation.
    - Equalizing.
  - (2) Line Battery (Battery S.S.)
    - Peak Work.
    - Emergency Reserve.
    - Voltage Regulation.
    - Improving Line Voltage, Copper Saving, Offsetting Rotary S.S.
    - Equalizing

A cell on open circuit will show approximately 2.08 volts, which is practically independent of the state of charge of the cell. This is frequently known as the floating voltage of a battery; in other words, a cell of storage battery, if connected across a potential of 2.08 volts, will neither charge nor discharge.

In order to maintain a constant rate of charge or discharge from a storage cell, the e.m.f. of the source of supply or demand must, throughout the charge or discharge of the cell, be increased or decreased so as to conform to the charge or discharge curve at that particular rate. As an illustration, let us suppose it is desired to discharge a cell at a rate of 100 amperes for eight hours, assuming that to be the capacity of this particular cell; if it is first con-

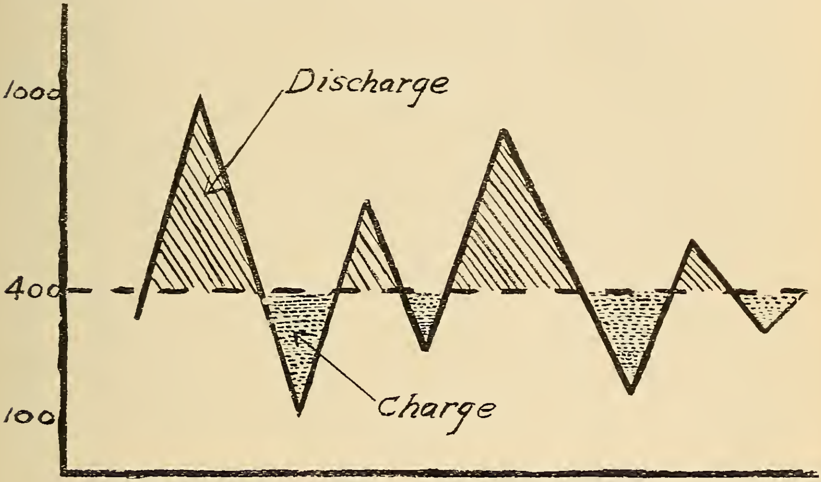


Fig. 1.

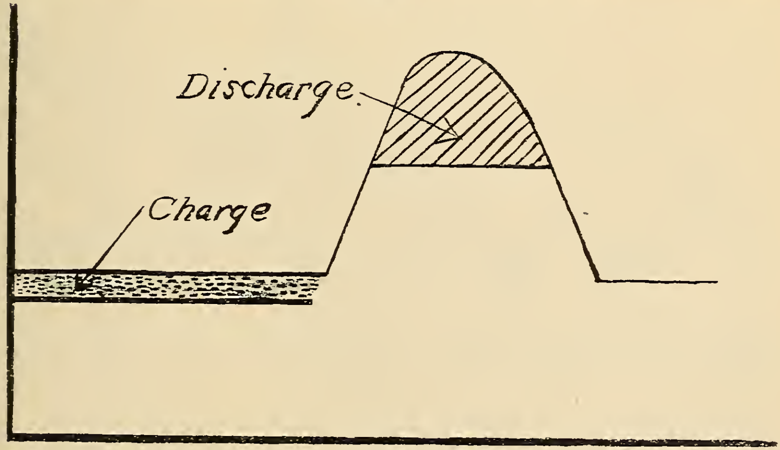


Fig. 2.

nected across a potential of 2.08 volts, it will neither charge nor dicharge. If this potential is instantaneously reduced to 2.04 volts, the cell will discharge at a rate of say 100 amperes, more or less, according to the state of charge, temperature, etc.; that is, the instantaneous drop in cell voltage will be 0.04 volts when discharging at a rate of 100 amperes. This first drop in voltage is practically entirely due to the internal resistance of the cell. As the resistance of the cell in question is approximately 0.0004 ohms, under the above conditions the cell must be connected across a potential of 2.04 volts, when it will begin to discharge at a rate of 100 amperes. As the discharge goes on, the e.m.f. across the cell must be reduced until at the end of eight hours it will have reached the final voltage of that particular discharge rate; that is to say, in order to keep the discharge of this battery constant at 100 amperes for a period of eight hours, we have gradually reduced the voltage of the circuit to which the battery is connected so that the curve of voltage maintained across the cell throughout the discharge is the eight-hour discharge curve of the battery. If these points are thoroughly understood, there should be no difficulty in understanding the operation of such auxiliary apparatus as is necessary for the control of the battery. Battery regulation may be generally divided into two classes, automatic and hand regulation.

AUTOMATIC REGULATION.

In cases where it is necessary to make the battery charge or discharge suddenly and for short intervals of time, automatic regulation is required. This is necessary in batteries classed under the headings, "A 1" and "A 2," where current regulation is to be ef-

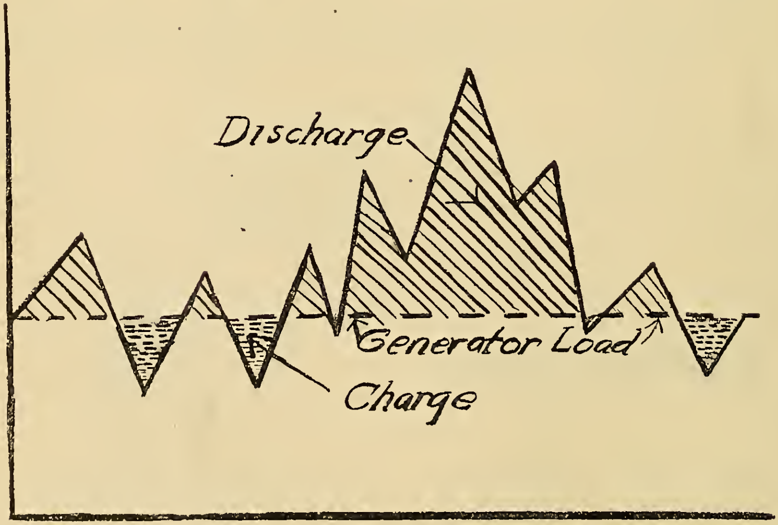


Fig. 3.

fected. As a matter of fact, practically all batteries in railway work, whether power house, sub-station or line batteries, are required to give current regulation, even if primarily installed for some other purpose, such as peak work. Therefore, in this class of service, the auxiliary apparatus must be such as to automatically regulate the charge or discharge of the battery, causing it to discharge at intervals of heavy load, and charge at times of light load. This is usually accomplished by means of a booster, although in some line battery applications no booster is used, as will be explained later. In power house or sub-station batteries, the type machine in most general use is known as the regulating shunt booster. The operation of this is as follows:

Referring to sketch 5, the battery in series with the armature of the booster is connected directly across the generator or rotary bus. The booster in this case is a specially designed shunt wound machine. Let us suppose that the average load on this sub-station (sketch 1) is 400 amperes, and that it is subjected to heavy and sudden fluctuations of load, varying from a maximum of 1000 amperes to a minimum of 100 amperes; the fluctuation above the average therefore amounting to 600 and the fluctuation below amounting to 300 amperes. The function of the battery in this case is to relieve the station of these fluctuations, maintaining a constant load on the generator or rotary approximately equal to the average of 400 amperes.

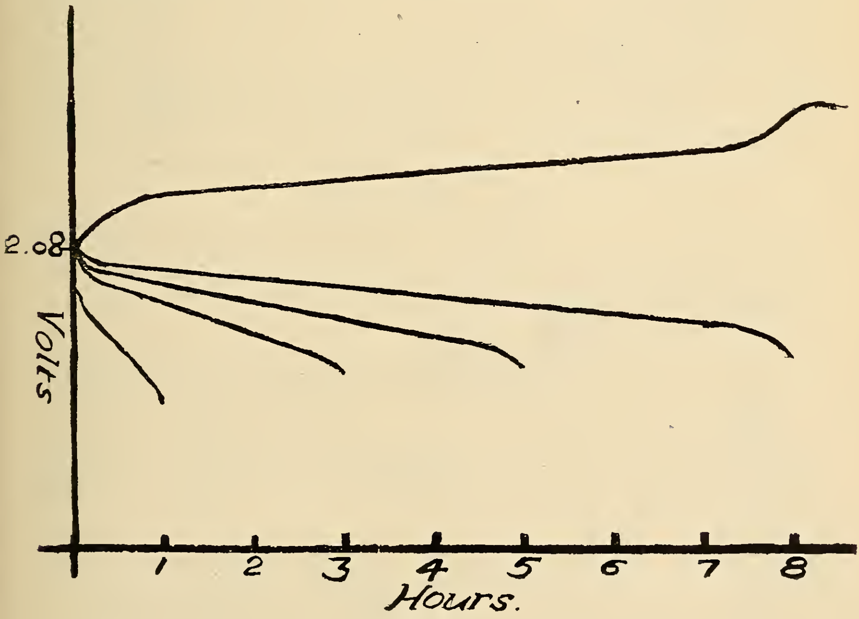


Fig. 4.

As we have already found from the discussion of the characteristic of a storage cell, in order to make this battery discharge at a predetermined rate of 600 amperes for a predetermined time of, say, 15 seconds, the voltage supplied across the battery terminals must be dropped an amount equal to the drop in battery voltage under this discharge and for this period of time; in other words, let us assume that this particular battery, when discharging at a rate of 600 amperes for 15 seconds., will drop 10 per cent. in voltage. Since the floating voltage of the battery is 600 volts, its minimum voltage under this discharge will be 540 volts. The booster must, therefore, give 60 volts, and its potential must be in a direction opposite to that of the station bus, so that the required 540 volts will be applied across the battery terminals. In order to make the battery *charge* at a predetermined rate for a predetermined time, the booster must generate a voltage equal to the increase in battery voltage above its floating point, and the potential of the booster in this case will be in the same direction as the bus potential, thus giving the necessary charging voltage across the battery terminals.

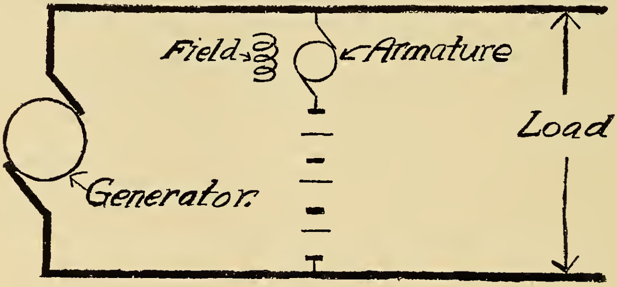


Fig. 5.

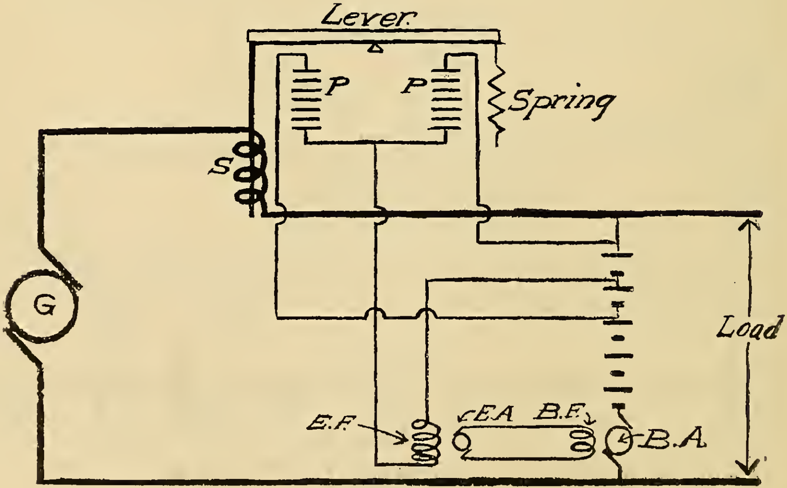


Fig. 6.

These automatic changes in field excitation and the reversals of the field are, with a regulating shunt booster, accomplished by means of a carbon regulator. This regulator (sketch 6) consists of two piles of carbon discs connected in series across a part of the battery, this battery potential causing a continued flow of current through the carbon piles. The booster field is excited by an exciter, the field of which is connected from a point midway between the carbon piles to a point on the battery midway between the connections of the carbon piles to the cells. A lever is carried on a fulcrum located between the two piles. From one end of the lever is suspended the iron core of a solenoid, S, which solenoid carries the output of the generator; at the other end is an adjustable spring which, when the battery is required for current regulation only, is so adjusted that its pull will exactly equal the pull of the solenoid at the time of the average load on the plant. The operation of this regulator is based on the principle that the contact resistances between two carbon surfaces is decreased by pressure. When the average load on the station obtains, and the pull of the spring exactly balances the pull of the solenoid, the resistances of the two piles of carbon are the same, and no current flows through the fields of the exciter. Now, if the current from the generator increases by a very small amount, the increased pull exercised by the solenoid will compress one pile and reduce the pressure on the other, thus destroying the equilibrium and causing current to flow through the exciter field in such a direction as to give the necessary excitation of the booster field in the proper direction for battery discharge. Conversely at times when the load on the station is less than the average, a slight decrease in the current through the solenoid compresses the *other* pile, thus causing a reversal in direction of the current flowing through the exciter field, and giving the booster an e.m.f. in the direction of charge.

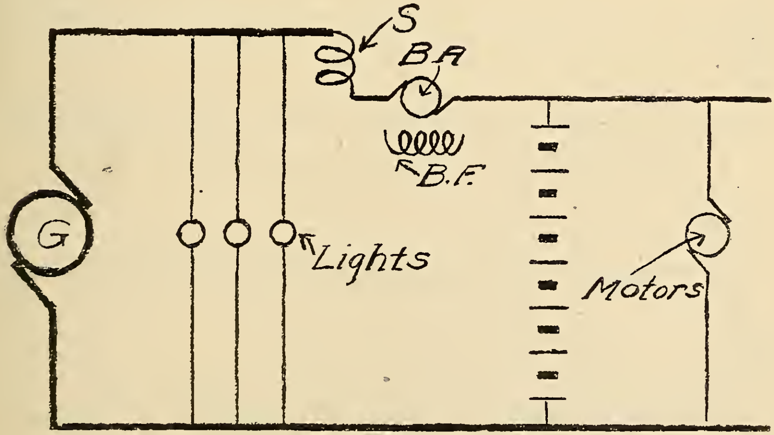


Fig. 7.

Under the heading "Line Batteries," automatic regulation may be effected, first, by means of a booster; and, second, by means of the line drop, the battery in the latter case floating directly across the line without any auxiliary apparatus. In the first case, the type of booster used is a specially designed compound wound machine (sketch 8). When the average load obtains on this particular line, and therefore the average voltage exists at the battery, the battery should float; that is, should neither charge no discharge, and the booster voltage at that time will be zero. Now if a heavy load is applied to the line, a slight drop in the line voltage at the battery will start a discharge from the battery; this discharge passing through the series fields of the booster builds the voltage of this machine up to the required amount.

In the second case of Line Battery operation, which is illustrated by sketch 9, while the average line voltage obtains at the battery, the battery floats; a heavy load applied to the line causes a drop in voltage at the battery, thus causing a batttery discharge to the line. It is obviously impossible by this means to relieve a line of the same percentage of fluctuations as can be accomplished by the use of a booster in conjunction with a battery, as the characteristic of the battery in the latter case is similar to that of a shunt wound generator applied at this point, while in the case of the line battery operating with a booster, a practically constant potential is applied across the line at the point where the battery is installed.

In certain classes of power work where the load consists of a steady lighting load, and a fluctuating load, due to the operation of motors, another type of booster known as the constant current booster is frequently used. This is illustrated in sketch 7. A carbon regulator solenoid in series with a booster armature is inserted

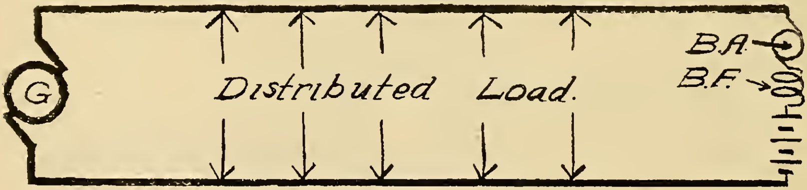


Fig. 8.

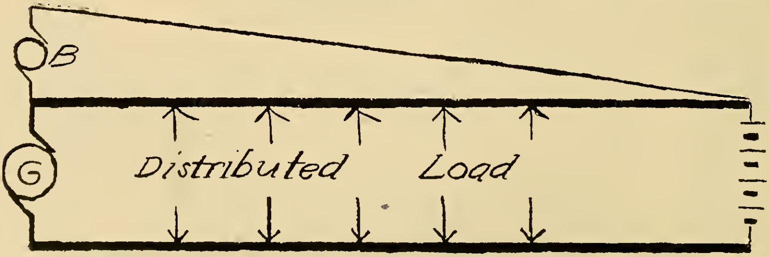


Fig. 9.

in the bus between the steady load and the fluctuating load, the battery being connected across the fluctuating bus. This booster passes continually from the generators the average motor load; its field is varied with the load by means of a carbon regulator, which was described in the case of the regulating shunt booster. By means of this booster, the potential of the battery bus is made to vary in acordance with the battery characteristic. In this case the power bus voltage varies with the battery of course while the lighting bus voltage remains constant.

The above covers in a general way the more common methods of obtaining automatic regulation of battery charge and discharge.

HAND REGULATION.

In cases where the battery is required to carry a sustained peak, as illustrated in sketch 2, that is required to discharge continuously over a comaparatively long period, with little or no compensating charge during this period, the control of the battery and discharge is accomplished by hand regulation. As stated above, nearly all batteries in railway or power service are required to give automatic regulation, on account of the sudden fluctuations of load. For this reason a booster is required with practically all railway and power batteries. If, in addition to regulating the fluctuating load, the battery is required to give a sustained discharge (as shown in sketch 3), that is accomplished by raising the booster voltage in the direction of discharge from time to time during the peak, as the load increases and as the battery voltage falls off, this being accomplished by hand operation of the field rheostat of the booster.

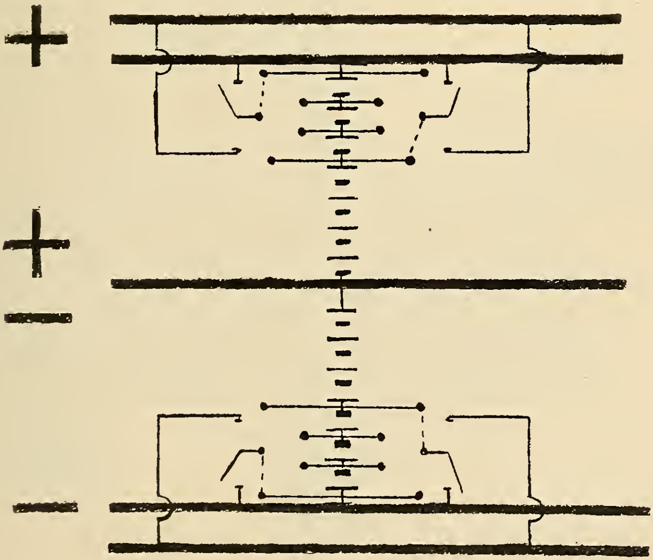


Fig. 10.

In case of lighting batteries, automatic regulation is seldom required, owing to the slow and long-sustained changes in load; therefore, booster regulation is not necessary on discharge, and the regulation of the *discharge* is usually controlled by means of end cells. This is illustrated in sketch 10. In this case let us suppose the main battery is floating across the bus neither charging nor discharging. Then let us assume that, with a discharge at a certain rate, an initial drop of ten volts would occur in the main battery. In order to compensate for this drop, such a number of end cells must be placed in service that the voltage of these end cells, with the battery discharging at this particular rate, will be equal to the drop of ten volts in the main battery. On sketch 10, I have shown two end cell switches on each side of the system. Frequently in Edison work two or more bus pressures are maintained. The battery with this system of connections can be operated on two spearate busses, the end cell switch on one side being cut back and the other run forward so as to give the desired voltage on the two busses. In larger service on Edison work, charging is accomplished by means of a shunt wound booster. This booster may be connected in series with one of the end cell switches, the other end cell switch being connected directly to the bus and cut back more and more as the charge goes on, so that the battery may be kept floating directly on the system even while charging.

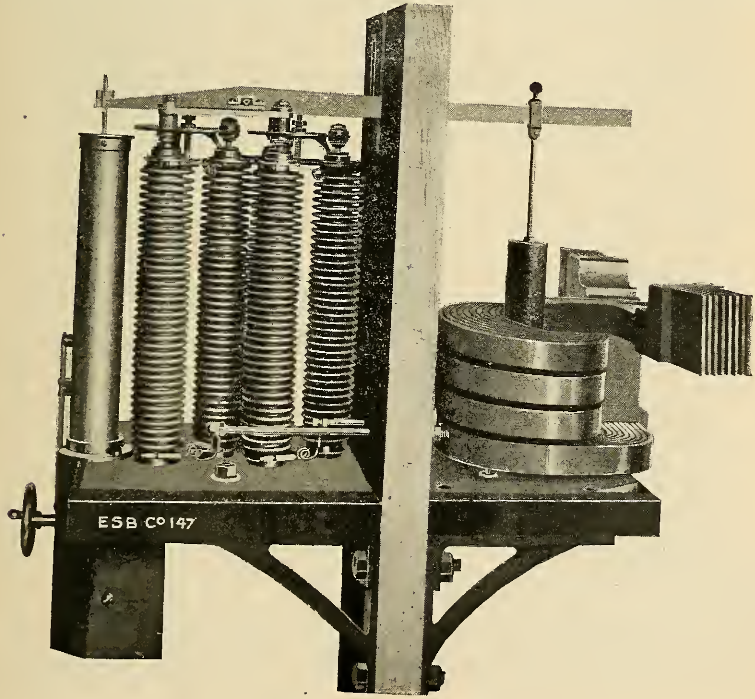
Part Second.

With respect to the functions of the storage battery: First, in railway service; I might say that on the smaller railway systems the principal function is usually that of current regulation; that is to say, relieving a plant or sub-station, or both, of fluctuations of load and maintaining a constant load on the generating apparatus and rotaries. As the systems increase in size, peak work by batteries become more and more important, and in the largest systems it is distinctly the principal feature of the battery.

In the case of d.c. railway power houses, the batteries by relieving the station of fluctuations allow the engines in service to operate at a steady and economical load. In practice, if we assume that the heaviest fluctuating load that small d.c. unit will carry, without constant trouble, is twenty-five per cent. in excess of its continuous rated capacity, and assume that the momentary fluctuations of load are double the average, it is evident that the generators, if carrying these fluctuations, will not work at a load factor above 62.5 per cent. It is, therefore, obvious that by using a battery in this class of service the capacity of the station can be materially increased, and frequently the load factor of the units in operation may be greatly improved as the fluctuations are often of such extent, as to necessitate the operation of more than one unit without the battery. The battery by obviating the necessity of the operation of, say one unit, of course, eliminates the constant losses incident to this unit, and increases the efficiency of the remainig units by improving their load factor, thereby permitting the station to give the same output with less loss, or a greater output with practically the same loss.

The losses due to conversion in the battery are almost negligible as compared to the increased economy of station operation, since the current converted is but a small percentage of that generated, the main point being that the current is stored when not needed, and given out at a time when it will be of the greatest value. In the case of batteries installed for regulating work in sub-stations, not only the rotaries, but static transformers, high tension transmission lines, alternators, engines and boilers, are relieved of the load fluctuations, thus insuring a load factor on the system closely approaching ideal conditions, and frequently resulting in a reduction in the number of boilers, engines and rotaries necessary for the operation of the system.

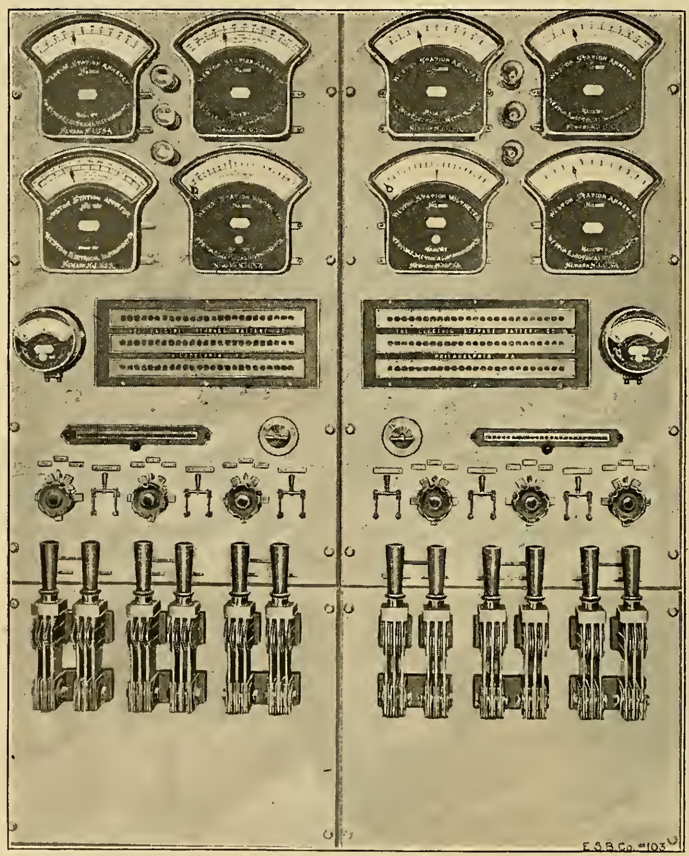
In small water power plants, the regulating feature of the battery is exceedingly important as the capacity of a water power plant for a given speed is fixed first, by the maximum demand, which in many cases is two or three times the average. Therefore, the battery by relieving the load fluctuations in this case permits the operating company to get the maximum value and output from its water power



The Carbon Regulator.

the battery also acting as an excellent governor for the water wheels. In water power plants supplying a fluctuating railway load and a lighting load, or in rotary sub-stations furnishing these classes of service, the battery eliminates the fluctuating voltage conditions on the lighting service due to the variation in the railway load.

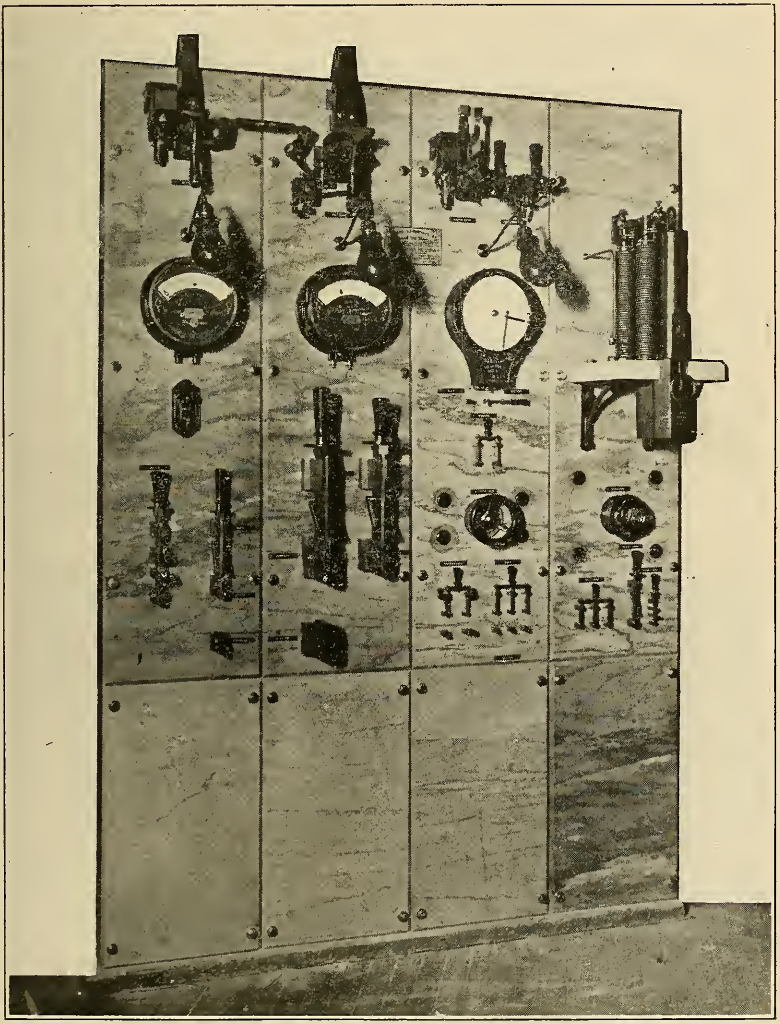
On suburban and interurban electric railway lines, the line batteries will frequently save more than their cost in feed wire, which would be necessary to produce the same line voltage conditions, or where the average load of a line is small, the battery will often offset a rotary sub-station. By the installation of a booster at the power house in conjunction with a line battery as is shown in sketch 9, the discharge and charge of the battery may be controlled by a hand adjustment of the booster rheostat, no regular attendant being necessary at the line battery, while the item of attendance in the rotary sub-station is considerable.



Battery Switchboard for Edison Three-Wire System.

The value of the line battery as against additional copper, lies in the fact that the copper with the battery has only to carry the average current, while without it sufficient copper must be installed to transmit the maximum current, with a drop in voltage which will not be prohibitive to good operating conditions.

In larger railway work, such for instance, as the surface and elevated roads in large cities, there is a pronounced peak caused by the traffic to and from the business center, the length of this peak varying from two to sometimes three or four hours. Batteries



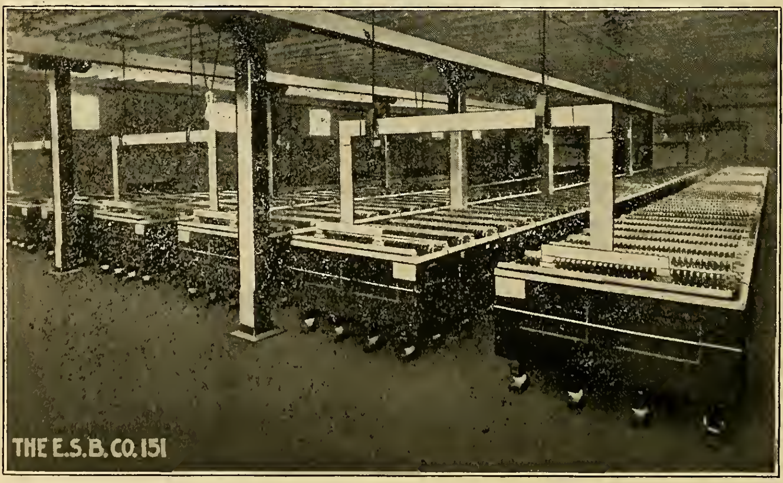
Battery and Booster Switchboard for Railway Power House or Sub-Station (showing Carbon Regulator on end panel).

installed in the power house to relieve the station of these peaks greatly improve the load factor and materially reduce the cost of operation of the station, besides offsetting an equivalent or even greater amount than the cost of the battery, in generators, engines and boilers. In a number of cases, such as the elevated roads in Chicago, it has been advisable to install the batteries on the line rather than at the power house. In this location they not only relieve the power house of a sustained peak during the morning and evening, but also relieve the feeder system of this peak. In a case that I have in mind in Chicago, the cost of the battery was entirely offset by the amount of copper that would have been necessary if it had not been installed.

Where operating companies purchase, instead of generating their own electric power, the rates are usually on a maximum demand basis, and it is, therefore, to the advantage of the consumer to keep down the peaks. In a number of instances the annual interest and maintenance of storage battery installations have been more than offset by the annual depreciation in the power bills, due to the reduction of the power demand.

The emergency value of the battery in railway service depends on the proportion of battery capacity to the load, and besides this, depends largely on the class of service; for instance, batteries in sub-stations on interurban work, even if installed for regulating work only and of comparatively small capacity with respect to the generator and rotary equipment, have at least sufficient capacity to move the cars in the event of shut-downs in the sub-stations, to the nearest station, thus obviating the possibility of cars being stranded in the country between towns.

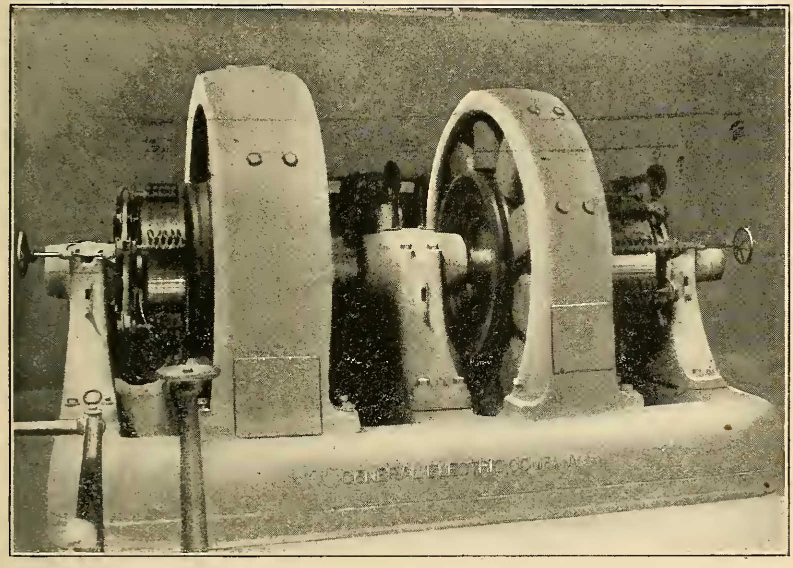
In lighting work, such as the Edison service in our large cities,



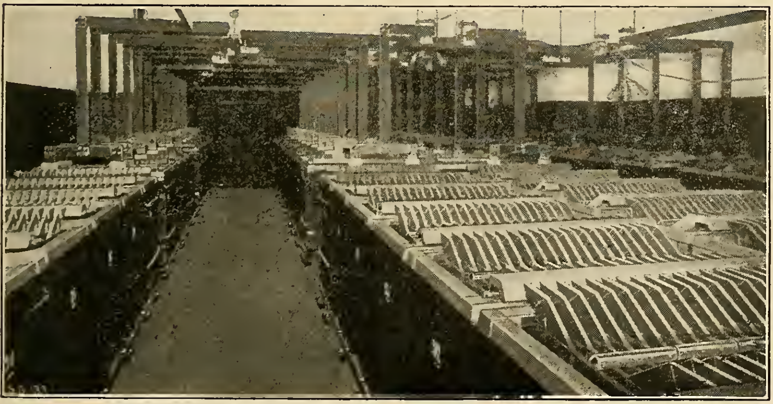
Railway Battery.

the same arguments for storage batteries for peak work would hold as in railway work.

In the case of sudden, unforseen demands for power, such as frequently occur on dark days, the batteries are instantly available for furnishing power until additional generating apparatus can be placed in service, thus not only insuring satisfactory service conditions, but often effecting a material saving in fuel, by obviating the necessity of operating additional boilers and generating apparatus in anticipation of unforseen loads.



Regulating Booster.



Battery for an Edison System (showing end cell connection).

DISCUSSION.

Mr. P. Junkersfeld, M.W.S.E.: I have been much interested in Mr. Waring's paper and the manner in which he has presented it. I doubt whether many people who ride on our surface and elevated railways and who have electric lighting service, realize the value of the storage battery. I believe it has been called "the watch dog of electrical service," and it is very aptly termed so. It is something that lies there quietly in many sub-stations and as long as the harness is on it is ready for work.

The storage battery has, as Mr. Waring pointed out, a number of advantages. It can be used for regulation or for peak work. In lighting systems in large cities it is used very largely for emergency service, and for that reason the companies feel that they want to have the batteries fully charged all the time, even though sometimes there might be economy in discharging.

The battery also ought to have quite a field in large manufacturing enterprises, where the cost of power is a very small part of the total cost of production, but where, you might say, everything stops when the power is off. That is a feature which will be recognized more and more as time goes on, not only for manufacturing establishments operated on direct current, but also on alternating current. Developments, I am informed, are well under way with which it is feasible to get this valuable storage battery protection for alternating current service.

There is another application of the storage battery that Mr. Waring has not mentioned, and which I hope he will tell us about; that is, the use of storage battery locomotives for industrial work—intermittent switching in manufacturing establishments and large yards—a class of service for which the battery seems particularly well adapted. Of course, it would have its limitations if the switching were of such character that heavy loads must be moved continuously, but there are many cases where it should find proper application.

Mr. Waring: The use of the battery in that class of service is largely dependent on the work that the locomotive has to do, and on the charging facilities. In a switching yard, where the work required would be continuous for a period of seven or eight hours, with no time for charging during that interval, the weight of the battery, besides its cost, would probably be prohibitive. In the case of a certain manufacturing establishment, where they have a switching yard, it was found convenient to have one of these locomotives for shifting purposes. In that service the car runs from one end of the yard to the other in about two minutes; it takes another two minutes to unload; then goes back, and this is kept up for the entire day. We have suggested in that case a shoe on the car, and as soon as the battery gets to the end of the line the charging could be done while the cars are being unloaded. The run is so short that in this case the battery is alternately charging and discharging for short intervals, there is therefore very little battery needed for this service. In a case of this kind the battery can be kept down to a suitable size with little expense.

While I have the floor, I might say that there is one point I did not cover, simply because of lack of time and the fact that it is a lengthy subject. Mr. Junkersfeld has referred to this—the application of the battery to a. c. work. The battery in that class of service, is in its infancy in one sense, still, during the past two years, the company with which I am connected has installed several batteries for this work. We have closed a proposition with the Indiana Steel Co. in connection with the new Gary plant. In one of their rolling mills the load was to vary from 4,000 H. P. to 14,000 H. P.; the fluctuations coming on with very great rapidity. The power house at Gary will consist of seven alternators and two d. c. power machines. They will supply d. c. at 200 volts and also alternating current. The batteries on this system will be connected to the d. c. bus through a booster, such as shown on sketch 5. To that extent it is exactly similar to a battery in a railway power house. It will also be connected through a specially designed rotary and transforming apparatus to the a. c. mains, and by means of special regulating devices which are governed by the fluctuations in the a. c. load, the battery can be made to discharge into the rotary at the heavy load, or take a charge from the rotary at times of light load on the alternating system. A similar installation to this is at the Youngstown works of the Carnegie Steel Co. There is also another a. c. plant now in service in the state of Washington. In that case the source of supply is three phase 60,000 volts and 60 cycles. The road is a single-phase road, operating at 25 cycles. The battery is installed in a frequency changing sub-station. In this station they installed one 60-cycle alternator, and one 25-cycle alternator, on the same shaft with a d. c. machine. The battery is connected across the d. c. machine and is regulated by a carbon regulator, as described, only in this case the solenoid of the carbon regulator is in the a. c. supply mains. A slight increase going through the solenoid causes a battery discharge. The d. c. machine then acting as a motor driven by the battery and giving the necessary excess power to the shaft of the motor generator set. Conversely, at times of light load, the d. c. machine acts as a generator and supplies power to charge the battery, thus keeping a practically constant demand on the supply line.

A Visitor: Where there is a very small leak in a cell, what is the best way of fixing it?

Mr. H. M. Beck: For the actual tank repair there is no temporary way. Our practice is to burn a patch of lead right across over the hole. The cell is cut out for the time being, and the sooner the better. Naturally, the acid gets into the wood work and rots it. There is no temporary means of repairing a leak.

Mr. G. H. Atkin: We are very glad to have a chance to tell the members of this Society how much can be done in electrical work in an engineering way, and also in a commercial way, by putting in a storage battery system. I hope that those present will not hesitate to ask questions from the engineers here on this very important subject. I think you can learn a good deal that you ought to know about batteries, and if it were a question of trying to sell you a battery system I should feel a little more in my element in explaining their conditions, their manufacture and their care.

Mr. C. A. S. Howlett, M.W.S.E.: Mr. Waring touched on the plant at Gary, Indiana. If he would tell us the approximate size of the storage battery equipment, I think it would be of interest to those present.

Mr. Waring: It is a "71 R.," about 250-volt plant. There are two batteries to go in parallel, each 250 volts and each having a capacity of 4200 amperes for one hour. In the beginning the battery plant will have a capacity of 8400 amperes for one hour, and if the present plans mature, the expectation is to double this.

Mr. F. M. Davis, JUN. M.W.S.E.: It is generally understood that in most cases the ultimate size or capacity of the telephone plant cannot be definitely determined at first, and that for storage battery plants for telephone exchanges, it is often customary to count on an ultimate equipment much greater than is necessary for the initial equipment. The question is to determine how much growth it is practical to count on in the initial equipment, and to what extent it is advisable to leave the ultimate equipment for future addition. As I understand it, it is cheaper to put in a given number of plates in the initial installation, than to put in part of them at first and add to the installation afterwards. There is an extra expense in adding later on. Moreover, there is a slight irregularity of chemical action immediately after the addition, due to the fact that part of the plates have been in use and part are new. To what extent is it advisable to put an investment into extra plates in the initial equipment in order to save a greater extra expense in adding them a year or two later?

Mr. Waring: As far as expense is concerned, the only additional expense the purchaser would be put to by installing new plates later on would be the additional labor expense of the second installation. Assuming that the plate prices are the same, it would be slightly greater than if installed originally, but in a battery of any material size this would hardly be considered.

Another expense would be, if the battery had been in hard service for some time, the grouping of the old plates, but as far as this cost is concerned, it is hardly worth considering in a large installation. As far as the operation is concerned, there would be no trouble from putting in new plates. Of course if one were expected to put in this addition, within short time, say a year, he would be justified in providing for it in the initial installation. But unless this were the case, it would be better to put in the increase later.

Mr. E. N. Lake, M.W.S.E.: I would ask if there are any figures showing the difference in efficiency between the two plants when using the rotary and when using the motor generator.

Mr. Waring: I have no definite figures, although I expect very shortly to have some. But one thing is very apparent: that is, with the battery on regulating work the losses are small as compared with the savings the battery effects. One thing is evident; if you take a battery doing regulation work, you are working at the left hand end of these curves. Your battery is dropping off in voltage only a small amount. In regulating work, the battery can work up as high as 90 per cent. efficiency.

Mr. D. W. Roper, M.W.S.E. : Mr. Waring in describing the methods of using batteries for different classes of service, has stated that it is customary for lighting stations to use the end cell method of regulation. Some years ago, at the International Electrical Congress in St. Louis, a very distinguished European engineer made some remarks on this subject, and spoke very highly of the English method of regulating by means of a booster. I would like to ask Mr. Waring what has caused this difference in the English and American practice?

Mr. Waring: That is a subject that I have not gone into at great length for the reason that in America the practice of regulation for end cell is absolutely standard. I think Mr. Junkersfeld can give us some information on this subject.

Mr. Junkersfeld: It is the practice in England, to a large extent to discharge lighting batteries through boosters. One of the reasons, and perhaps the chief reason for not using a booster in this country, is that American engineers feel that the battery is, in a large measure, a reserve; that being the case they want to have no moving apparatus between the battery and the line, or at least the smallest amount possible. If the booster is used, it is simply another link in the chain and one that may give way. With the end cell switch method, the batteries are connected directly to the bus bar, and there is less chance of anything giving way.

From the point of operating economy and of first cost, that matter was investigated somewhat here in Chicago, within six months, after the discussion in St. Louis referred to. Mr. Roper was one of the two men who were delegated to make that investigation, and he can probably give you some of the results in detail of that investigation.

Mr. Roper: In asking the question I was expecting to get a somewhat more extensive opinion from the storage battery engineers on this subject.

The investigation of which Mr. Junkersfeld speaks was made for the purpose of obtaining a comparison of the investment and operating cost as well as such operating features as could be learned with a limited experience. A battery was operated by each of the two methods for a period of several months and a careful record was kept of losses involved in charging and discharging the battery. The first cost of an installation, using the booster method of charging and discharging is somewhat less than the installation of equivalent size, using a booster for charging and end cell switch for discharging.

The former method has, however, considerably greater losses as the booster operated while the battery is discharging and at other periods when floating, as well as when the battery is being charged. The operating cost of the reversible booster method will therefore be greater than for the end cell switch method and this difference will increase with the use of the battery.

In order to obtain information as to what constituted the average use of a battery, we obtained figures from the leading American users of batteries for lighting work, and found that the annual cost of the end cell switch method of discharging is less than the reversible booster scheme for nearly all conditions of American practice. If, instead of using a booster for charging the battery, arrangements were made for installing a generator, or a rotary which could be operated at a sufficiently high voltage to charge the battery, and thus save the installation of the booster for charging purposes, the end cell switch method would be cheaper than the booster method under all American conditions.

Mr. Waring: I would ask Mr. Roper, in the comparison that was made between the end cell switch method and the booster method, what ampere capacity was figured on for the booster? Suppose you had a battery which was rated at 1,000 amperes for one hour; what booster capacity did you figure on in that comparison?

Mr. Roper: In order to obtain the actual figures on that point, we assumed that the booster would be called upon to carry the capacity of the battery—the one-hour rate for one hour—and it was also specified that the booster should be able to carry the 20-minute rate of the battery, for 20 minutes. The figure on the cost of the booster was an actual quotation from a manufacturing company.

Mr. Junkersfeld: I might explain regarding this question that in England the battery is in most instances not connected to the system 24 hours a day, as here. They start up and run during their peak, and then shut it down again. Furthermore, instead of trying to maintain the service, as Mr. Waring has indicated, in England there is usually an overload circuit breaker on the booster, and if a short circuit on the system is heavy enough to trip the breaker, the electric service is interrupted. In this country an effort is now made to keep the storage battery connected to the bus bars at all hazards. In England the standard of electric service is improving, and as it improves they are getting around to this end cell switch method of control, which allows them to leave the battery on 24 hours a day if they wish, and which they cannot do so economically with the booster.

Mr. Beck: In regard to this subject of the booster, there is one case which we take great care to safe-guard. If for any reason the motor of the booster is thrown off the line (through its circuit breaker, or otherwise), and the line voltage should drop considerably, there might be a heavy discharge from the battery through the generator end of the booster. Should the booster field be close to zero, we would have a case of a motor operating without any field, and there is danger of its running away, because the regular motor being off the circuit there is nothing to hold it back. As long as the motor is on the circuit, if you try to speed the booster up beyond a certain speed, the motor will act as a generator and hold it back. As a protection we use two means. In the first place, we put a circuit breaker on the motor as well as on the booster, and these two circuit breakers are connected either mechanically or electrically, so that if the motor breaker goes out it automatically throws out the battery also.

The second protection is a speed limiting device similar to the type used on rotaries, which is put on the booster shaft, and acts at a certain per cent. above the normal speed.

Another case is with lightning. A battery in itself is a very non-inductive path for lightning, and the result is that it seems as if, during a thunderstorm where the lightning is bad, it strikes the booster before the generators. We have had some cases where they have been burnouts due to lightning through the booster.

Mr. W. S. Taussig, Jun. m.w.s.e.: With normal conditions of service, what is the life of the plates in a storage battery plant?

Mr. Waring: It is largely dependent on the service. I think Mr. Beck can probably answer that question better than I can.

Mr. Beck: Mr. Waring has given me a most difficult question to answer, for the reason that I believe there are no normal conditions. It is very seldom we find two conditions alike, and the result is the life of the battery will vary through wide limits. In a general way I will say that the hardest worked batteries are in the peak railway service. They are worked both winter and summer regularly, two peaks a day, and there are cases where there are three peaks a day, which is the heaviest service we have to meet. Even in this severe service it seems hard to use up the plates in less than four years, and in lighter work their life is naturally longer. You can go up to almost any life. The figures run up to seven and eight years of actual service. In lighter types of railway and of telephone service, the life is sometimes eight and ten years. But in giving the life of storage battery plants we are always at a great disadvantage. Where batteries last eight or ten years, we must remember that they are of the manufacture of eight or ten years ago. Of the batteries made today we have, of course, as yet no data as to life.

Mr. W. D'A. Ryan: The discussion so far appears to center around rather extensive battery systems. I would like to ask a question in regard to the use of the storage battery in department-store lighting. I have in mind a case where they used about 1,000 kw. capacity, and wish to avoid piping the store for gas, but they wish to provide for an emergency. The object of this safe-guard is to prevent a panic in the dark. The proposition is to connect about 10 per cent. of the lights to a storage battery. This battery will furnish light in case the electric plant gives out or in case of fire; the lights will all be extinguished, except those connected to the battery. Furthermore, this battery will be used for lighting at night, the main plant being shut down. I would like to know if this practice has been very generally established.

Mr. Waring: We have put in a number of batteries to act as an emergency reserve for the lighting system. In the case of fire in a department store, such an arrangement might be made; one could figure how long it would take to clear the store. I should think it would be quite feasible to have a battery that would furnish sufficient light for say half an hour in case of an emergency, to get the people out of the building.

Mr. Taussig: A year or two ago some interest was manifested in the electric locomotive which had a gas engine, storage battery, and motors. I would ask Mr. Waring if he can tell us anything about that.

Mr. Waring: We put in on the St. Joseph Valley Traction Co.'s road (about 20 miles in length) a system of that kind, about 2½ years ago. We made a test on that car about a year and a half ago, and it seemed to be giving very good service. The car barn caught fire some three or four months ago and destroyed the car. The owner has now contracted for a larger car, to be operated on the same principle. The results of tests that I have made as to operation were very satisfactory. One thing that rather surprised me was the low power consumption that the car required. The car was pulling a trailer and I think the car averaged only about 40 watt hours generated per ton mile. We carefully checked these figures, which show economical operation. The cost of gasoline for running the equipment was very low. The engine was operated at about three-quarters of its rated capacity, the battery maintaining a very constant load on this unit. The operation of the car was also satisfactory from a purely operating standpoint. The car was in service for three years. There was no expense in connection with the battery in that time, and, as I uderstand it, no expense whatever in connection with the car. However, I do not think that scheme is going to revolutionize railroading. In this particular case the car made only two trips a day, and it would hardly seem a case for a complete generator equipment, over-head line, etc. Another car of that type is the Straug car, that ran from New York to Chicago; the operation of this car was satisfactroy as far as I know.

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SOME FEATURES OF CONSTRUCTION OF THE SOUTH SIDE ELEVATED RAILROAD

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Presented March 25, 1908.

The South Side Elevated Railroad Co., in order to meet the requirements of a rapidly increasing population within the limits of the territory covered by its line, has recently been making some extensive improvements in its existing line, as well as building several extensions into new territory in the southern part of the city.

The original line was built as a two-track structure southward from Congress St. to 63rd St. and eastward in that street to Jackson Park.

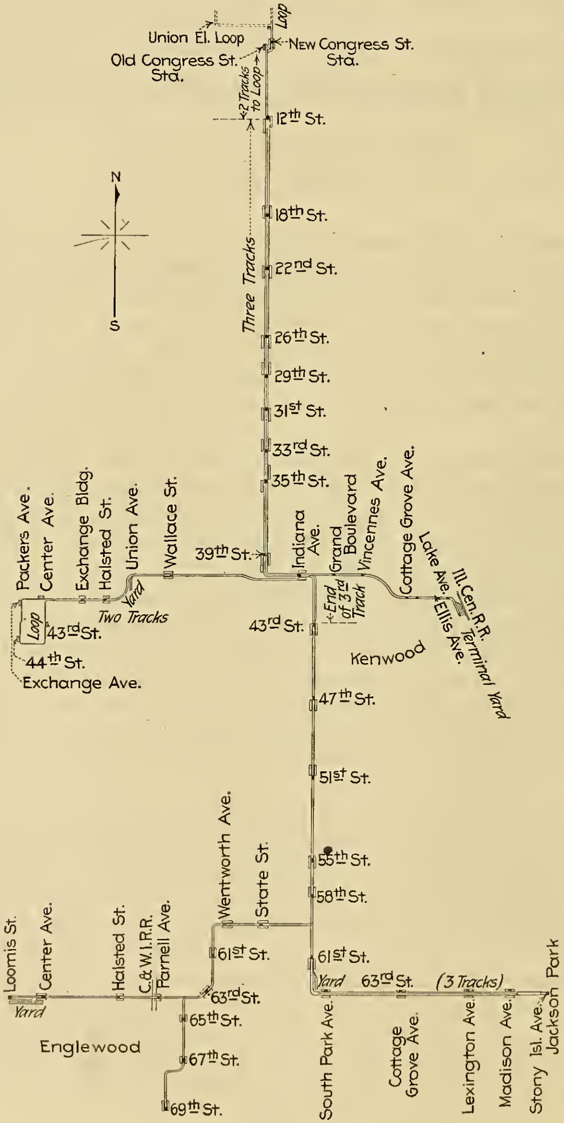
At the time when this original line was built (in the early 90's) the portion of the city which it traversed, especially from 39th St. southward, was rather thinly inhabited; the only immediate incentive for building so far southward at that time seeming to have been to reach the World's Fair traffic of 1893.

Following the construction of this line, however, owing to the exceptional transportation facilities which it afforded, the population contiguous to it, steadily and constantly increased with the years until finally it reached a point where, if additional facilities for a more rapid transit to the business center of the city were not provided, this increase of population would be checked, or the natural and normal growth would seek some other line or lines of transportation.

To meet these constantly increasing transportation requirements, it was finally decided to add a third track to the existing structure between 12th and 43rd Sts.; to eliminate existing sharp curvatures at several points, and to make several other important improvements, the nature and scope of which will be further described in this paper.

This additional third track, which was accordingly built, is used for local service, leaving the old east track (now the middle track) for express service, to afford the large patronage originating south of 43rd St. a rapid transit to and from the downtown district,—it being used for north bound traffic during the rush hours of the morning and for south bound traffic during the corresponding rush hours of the evening.

The original two-track structure from 12th St. southward to 63rd St. was built on private right-of-way—a 25 ft. strip cut from the rear end of the lots adjoining alleys; in order to widen the structure for the third track without making a further and expensive cut into



General map of South Side Elevated Railroad.

the private properties, it became desirable to acquire the use of the adjacent alley for the extended width.

Franchise for this use, was accordingly sought and acquired, and the alley was, in general, used for the addition. But, as a compensation for the privilege thus acquired, the South Side Elevated Railroad Co. was required, by the terms of the grant, to pave with asphalt its entire right-of-way and the alley adjacent, from 12th St. to 43rd St., and to throw the whole strip (40 ft. and more in width) open to the public for use as a thoroughfare, the Company merely reserving the fee to its own private right-of-way.

This requirement made necessary several other very important and expensive features of the work of improvement; namely, tearing away all the old stations, which, in the original construction were built on the ground; building new stations suspended from the structure with 14 ft. clearance above asphalt grade; and, finally, raising the existing structure at all stations to a height that would allow of the building of the station underneath, with this required clearance. A description of some of the interesting features of this work will be given later.

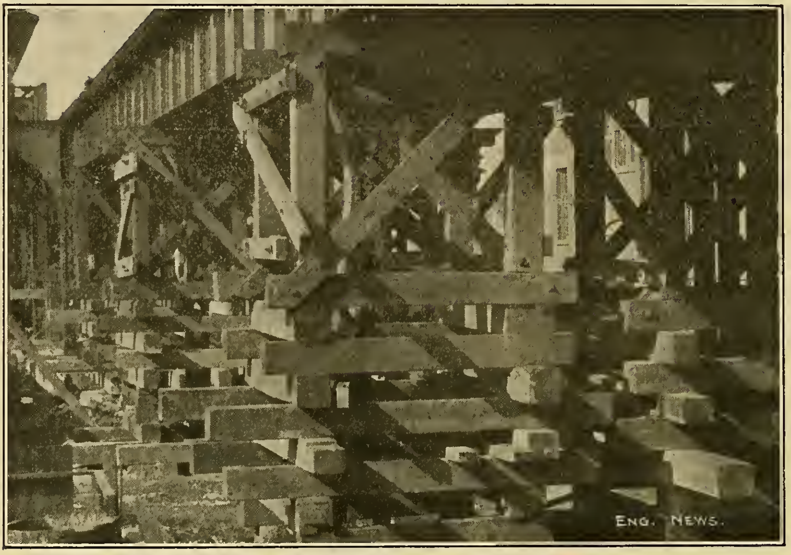
In addition to the work above enumerated, a two-track structure (now in operation) has been built into and through the thickly settled portion of Englewood, extending from the old line (as shown on accompanying diagram) at 59th St., west, south and west to 63rd and Loomis Sts., with terminal yards of seven tracks in width extending from Center Ave. to Loomis St.

Also a South Branch, extending from the above extension at 63rd St. and Stewart Ave. southward to 69th St. near Parnell Ave. The total length of the Englewood extensions being about 3½ miles.

Also, through arrangements with the Chicago Junction Railway Company, an extension has been made eastward in 40th St. to the thickly settled portion of Kenwood, with a terminus at 42nd St. and Oakenwald Ave. near the lake. This extension, 1¼ miles in length, is now in service and is operated on the elevated roadbed of the Chicago Junction Railway Company.

Also, by an arrangement with the same Company, a western extension of steel structure has been built in 40th St., joining the Main line of the South Side Elevated Railroad at Indiana Ave. and 40th St. and extending west to the Stock Yards with a Loop in the Yards. This extension, except the portion between Wentworth Ave. and Wallace St., adjoins the Chicago Junction Railway on the south. Between the two streets mentioned, however, the Elevated Structure is directly over the tracks of the Junction line, being built of cross-girder construction with columns supported on the retaining walls of the elevated roadbed of that line. This extension is now practically complete and will soon be put into service.

As a necessary part of the extensions and improvements above enumerated, the old terminal yards at 61st St. and Calumet Ave., originally on wooden trestle, have been entirely rebuilt of steel on concrete foundations; an extensive surface terminal yard has been built south of 63rd St., between Calumet and Prairie Aves., with an incline leading thereto; a large increase of power has been installed at the Power House at 39th and State Sts., and interlocking and block signals have been installed.

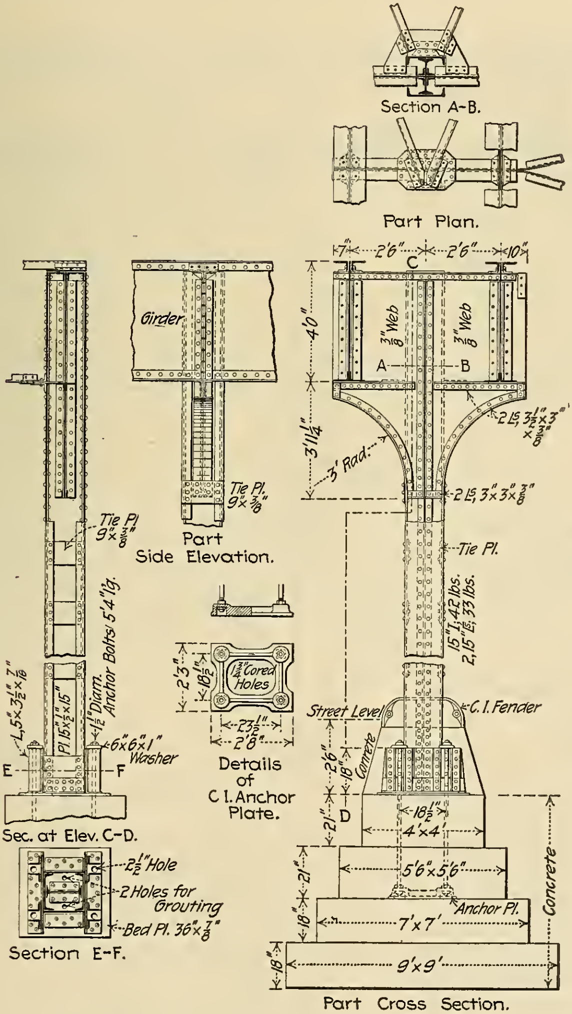


Structure on temporary blocking while elevating to new grade.

None of the work above enumerated presents any special or unusual engineering features, except the work of adding the new third track to the existing structure, embodied with which, as a necessary part of it, being the raising of the existing structure to the new grades required (from 3 to 6 and even 8 feet above the old grade); the changing of the existing alignment to eliminate sharp curvature, involving at many points entirely new construction; the tearing down of the old stations and building the new ones; and all the allied details of the work necessary to produce from the old structure the remodeled and extended and fully equipped structure as it exists today.

All this work had to be carried on in regular progression, and in such a way as not to interfere materially with the comfort and convenience of the traveling public; and under a train service of over 600 trains daily, with intervals of from one to three and one-half minutes. To meet these conditions and to prevent disaster or accident, the greatest care both in design and execution was necessary. To describe some of the more important and difficult features of this rather unusual piece of work, is the design of this paper, the novel character of the work constituting the warrant and excuse for this presentation.

In the entire work from 12th St. to 43rd St., designated as "Third Track" construction, about 660 new concrete foundations were required, 430 of which were for new Third Track and 230 were for renewals of old foundations, at station points and elsewhere, where changed conditions due to new construction called for a larger foundation support.

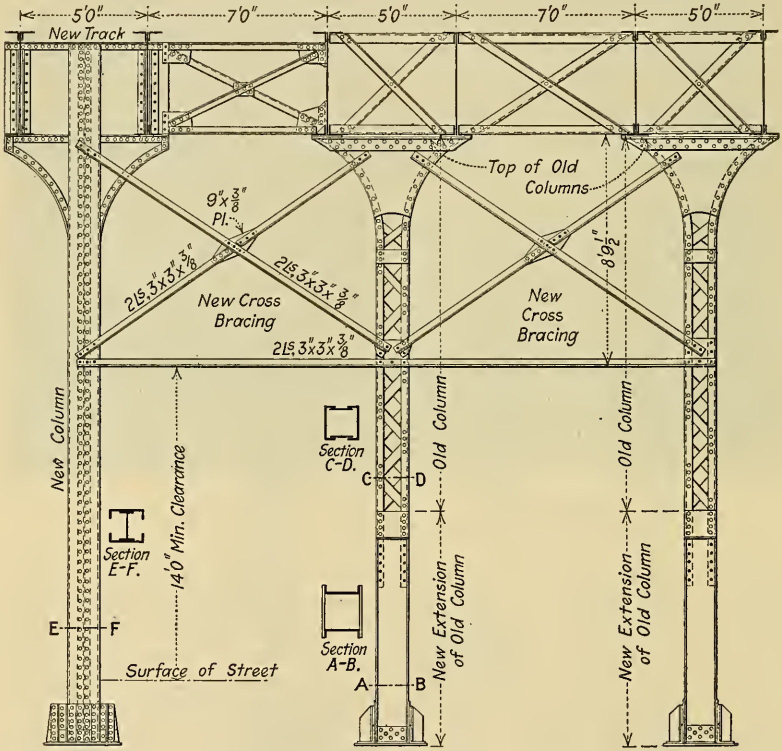


New third track column with enlarged foundation.

The old foundations were 7 ft. by 7 ft. in the bottom course while the new ones, in general, are 9 ft. by 9 ft.—thus affording a much larger supporting surface. As constructed the entire weight carried per foundation is approximately:

For Carload	72,000 lbs.
Structure	41,000 lbs.
Foundation	14,000 lbs.

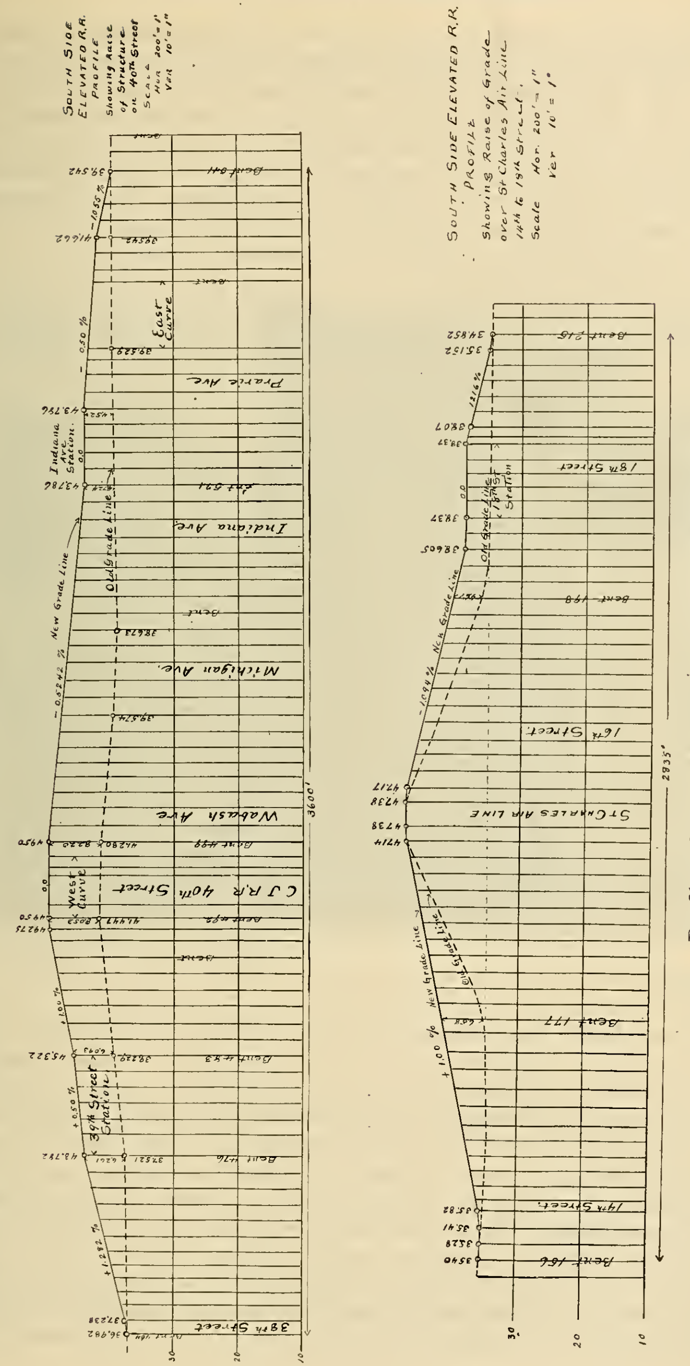
or a total of 127,000 lbs.—an approximate load of 1,600 lbs. per square foot on the underlying earth.



Construction for three tracks, with one new column and cross bracing.

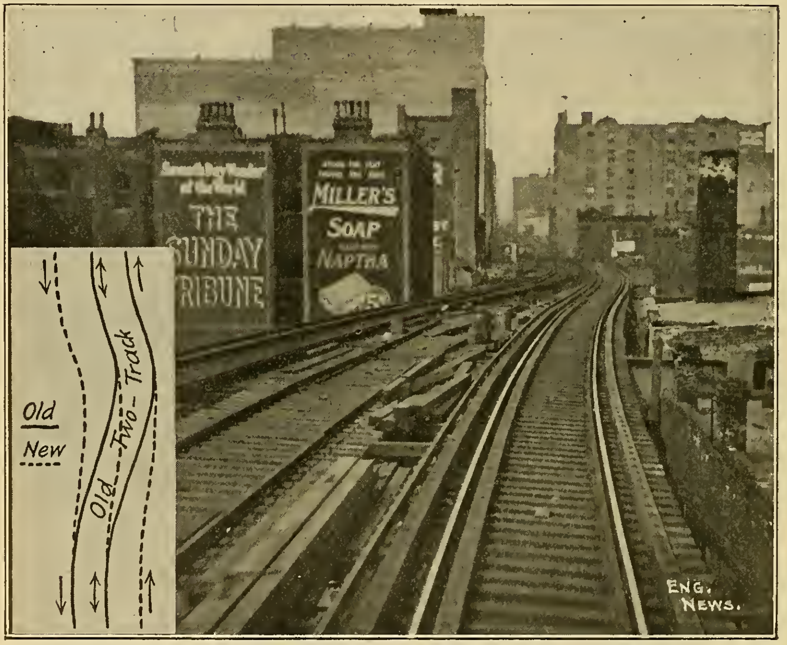
The 430 foundations for the Third Track were first put in, for the most part, in the fall of 1904 and the season of 1905. The foundations for renewals under the old structure were put in simultaneously with the blocking and jacking-up of the old structure.

One of the most extensive elevations of the old structure was from 14th St. southward over the "St. Charles Air Line" and on past 18th St. station, a distance of 2,800 feet. When the St. Charles Air Line was elevated, several years since, the South Side Elevated Railroad Co. raised its structure to give the necessary clearance.



Profiles of parts of South Side Elevated Railroad.

This raise was 13 feet at the "Air Line" with approaches of 2.17% grade, the columns being spliced to give the proper elevation. In the new raise an approach of 1% was given each way, beginning at about 14th St. on the north, as stated, meeting the old summit at the St. Charles Air Line, then running off on a 1% grade till the level required for 18th St. station was reached, thence running a level grade past the station platforms, and thence on a 1% grade to the original elevation at a point south of the station. The maximum raise to attain the new elevation was 6.58 feet.



Changing from 2 track to 3 track structure at 14th street, looking north.

The work of this elevation was commenced in December, 1904, and carried forward continuously to completion. New column extensions were riveted in place as fast as the jacking was completed, the old extensions being removed and used in other places where the additional elevation was such as to allow of their use.

At a point just south of 14th St., the old structure crossed from the east to the west side of the alley with a sharp curvature which was to be eased off at a later date in connection with the erection of the Third Track structure, which changed sides at this point. To provide for the necessary reconstruction for this, the structure was left on its blocking at this point. Also at the 18th St. station, where future reconstruction was necessary, the blocking was left in.

Elsewhere, as fast as the column extensions were riveted in place, the old structure was "landed" and the blocking was removed, leaving the old structure ready to receive the new third track.

At the several stations south from 18th St. the structure was similarly raised, attaining the required elevation opposite the station platforms with approaches of 1% each way. The elevation required at the stations, in general, ranged from 3½ to 4½ feet additional, requiring a stretch of from 800 to 1200 feet to make the elevation.

The work of elevation on 40th St., however, (which includes the 39th and Indiana Ave. stations) was exceptional, as between these two stations the elevated railroad crosses the Chicago Junction Railway, which also was elevating its tracks and required a raise of the elevated railroad structure of 8 feet for clearance.

To provide for this, and for the elevation at each of the stations mentioned, required one continuous stretch of elevation beginning at 38th St. at the foot of the north incline, attaining the required elevation at the north end of 39th St. station platforms, thence level past the platforms, thence up over the Chicago Junction road, thence descending slightly along 40th St. to a level grade past the platforms of Indiana Ave. station and so on, meeting the old grade of the structure at the south end of the curve at 40th St. and Calumet Ave.—a total length of raise of approximately 3100 feet.

Combined with this elevation there was also an easement in the alignment of both the east and west curves at 40th St., involving a new structure throughout as well as the necessary reconstruction at each station. The principal features of this complicated piece of work will be considered later on.

The blocking used in raising and supporting the structure was, in general, built up as follows: a practically continuous floor of 4 in. by 4 in. timbers was carefully leveled on the ground, on which was built a crib work of 12 in. by 12 in. timbers, laid "cob house" fashion, about 6 feet high, surmounted by a pair of trestle bents of 12 in. by 12 in. timbers of such a height as to reach the track girders, or cross-girders, as the case might be.

The crib work was built with eight of the 12 in. by 12 in. pieces projecting—four directly above the other four, forming an intervening space for the 30-ton hydraulic jacks used in raising the structure.

The working of the jacks in this space divided the crib work by a constantly increasing interval which was kept filled in by one and two-inch planks and by wedges till the interval thus created amounted to 12 inches, when the thin pieces were discarded and an additional 12 in. by 12 in. piece was inserted to fill the space. A 12 in. by 12 in. stick was then placed across the lower projecting ends to raise the jacks. The process was then repeated, and thus the work was continued till the proper height was attained.

One set of four jacks was used, raising one track at a time about 3 inches at a lift, if of center column structure, or 2 inches, if of cross-girder structure, was being raised. Each lift of one track was followed by a corresponding lift of the other track and so the two were carried up together.

With center column structure, no difficulty was experienced in handling one side at a time, but with cross-girder construction, a two-inch raise at a time was about the possible limit, and even at that, a few hitch angles were broken and afterwards replaced.

This work was all done under slow orders for trains with a flagman on top to stop trains, if necessary, till the amount raised could be caught and the jacks released, as the jacks would not stand the impact of trains.

This work was all so carefully and expeditiously handled that trains were rarely held more than a minute or two. No jacking was done during the "rush" hours of morning or evening, the train interval when the work was going on, usually being 2½ or 3 minutes.

Where new foundations were to be put in, to replace the old, instead of the lower course of 12 in. by 12 in. 10 ft. timbers, six 8 in. by 16 in. 30 ft. pieces were used for blocking, so as to span the required foundation excavation by a safe margin. These timbers were so spread as to give space for removing the old foundation and putting in the new, which work was all done while the structure was carried on this temporary support.

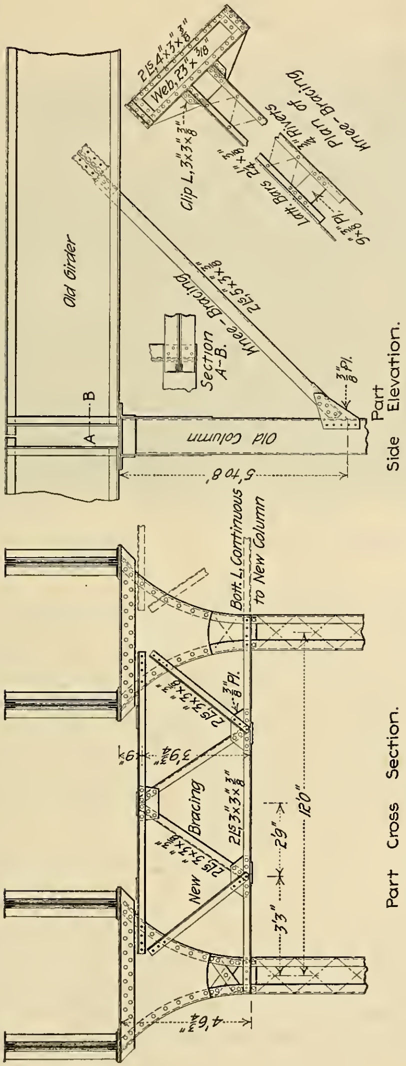
After the structure was carried to its full height, the old foot castings used in the original construction were knocked off by rammers dropped from a height of three or four feet, and new column extensions of suitable length, built up of 15-inch channels and plates, were riveted to place and anchored, after which the blocking was removed.

The additional height of the columns, due to the splicing, required additional strengthening to give the required rigidity to the structure. This was effected by a system of knee and cross-bracing at the top, so placed as not to interfere with the required headroom of 14 feet.

At each one of the old stations there was one bent of the old structure situated within the building, and in order to raise the structure and at the same time keep the old station in operation as long as possible, it was necessary to tear out a portion of the building and make temporary changes in the stairways so as to make the necessary space for blocking at the columns and to make the necessary renewals of foundations.

No two stations were alike and the difficulties encountered in making these changes required special devices in each case, but they were successfully met and overcome and the public was, in all cases, suitably provided for, during the progress of this feature of the work.

As soon as the raising of the existing structure past a station was completed, the method of procedure was to erect at once a small temporary station across the street from the old station, with land-



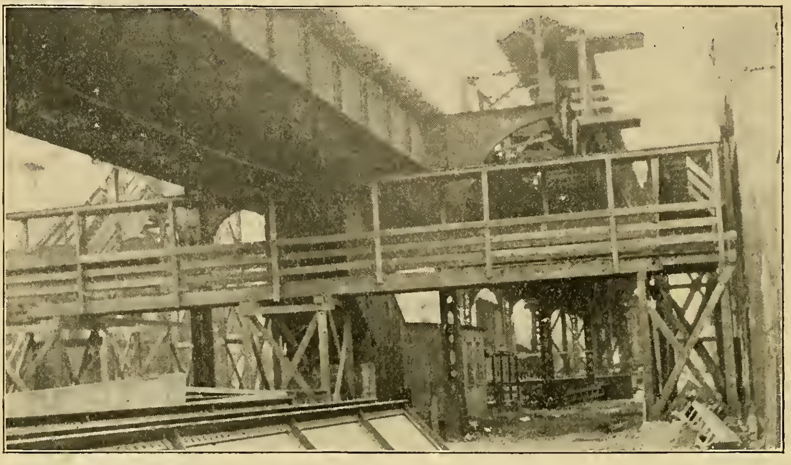
Part Side Elevation.

Part Cross Section.

Original spread top column construction with additional cross and longitudinal bracing where columns are extended.

ings and stairway connection with the station platforms, usually at the very end of the platforms. Traffic was then diverted to the temporary station, the old station was wrecked and space was cleared for the erection of new suspended station.

Meanwhile the third track structure had been erected on either side of the station and the track laid up to the station platform. The space which carries the new station consists of through girders in order to give the necessary headroom for the station, requiring two entirely new bents on new foundations.

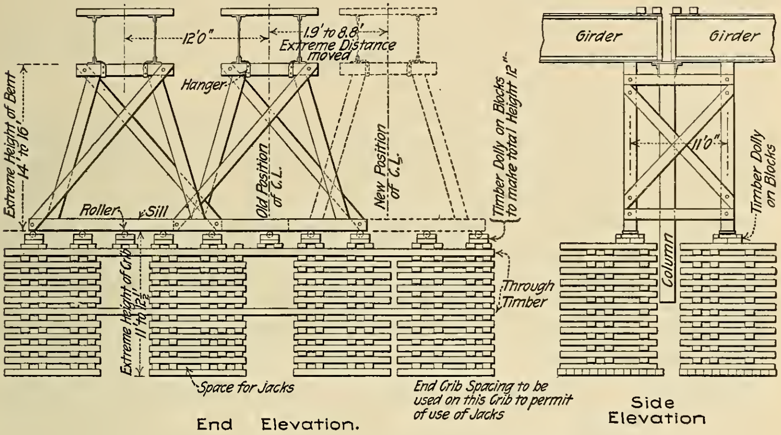


Temporary station and landing.

For this reconstruction, the blocking supporting the existing structure had been left in place. The track stringers on either side of this station span are now cut loose and cut off sufficiently to allow for the insertion of the new cross-girders, the new supporting columns are new erected from beneath and the cross-girders are launched endwise to place and riveted to the columns. Track stringers on either side of the reconstructed span are now riveted to the cross-girders, new hitch angles being provided for the purpose. Meanwhile crossovers have been installed between the two old tracks on either side of and beyond the limits of the station platforms.

Up to this time normal movement of trains has not been interfered with. At this stage, however, the west track between the two crossovers is abandoned, all traffic being diverted to the east platform. Old track and timber on the abandoned portion is now torn out and relaid with new material, old track girders of the west track at the station span are removed, new through girders are erected and riveted and new track is laid over the bridge to connection.

Double-track service is now temporarily resumed during which crossovers are interchanged preparatory to single-track movement on the other track, a process requiring usually three or four days. Single-track service is now installed on the west track; the old east track being torn up and relaid with new material. The remaining through girders of the station span are erected. The east platform is now jacked over 12 feet eastward onto brackets extending from the new third track columns. Middle and east tracks are laid through the bridge to a connection, and a temporary stairway, leading up to the east platform is adjusted to new connection. Two-track service is now permanently installed on the two outer tracks, leaving the middle track for future use in express service.



Cribbing and moving old structure laterally.

The suspended steel structure for the support of the new station is next erected, and the new station with landings and stairways is built entirely without hindrance to traffic, as the temporary station is maintained till the permanent station is entirely ready for use.

The occupancy of the permanent station with the demolition of the temporary one marks the completion of the work at any given station point.

The erection of the steel work at a station, and the construction of the station ready for occupancy usually required from sixty to ninety days.

Reconstruction on 40th St.

Special mention has been made of the reconstruction along 40th St. as involving many difficult features not encountered elsewhere on the work.

The old two-track structure at the east and west curves was built with radii of 100 feet, necessitating very slow movement of trains. An elimination of this undesirable feature was important, and a part of the work of reconstruction of this portion of the line was made to comprise an entire reconstruction of these two curves with radii of 182 feet in the central portion, compounding with curves of 500 ft. radius at the ends.

In order to secure the required curvature at the west curve, local conditions made it necessary to cut across the old structure in 40th

St., and to end the new construction at the east end of the new curve about 6 feet south of the old alignment in 40th St.; making it necessary to jack-over the old structure onto new foundations to meet the new structure, and to introduce curvature of easy radius at the pivotal point of this movement just west of Michigan Ave.

The course of procedure for the entire work of reconstruction of this portion of the line beginning at 38th St. and ending at the south end of the east curve in the alley between Prairie and Calumet Aves. was essentially as follows:

During the month of February, 1905, the old two-track structure was jacked-up to its new elevation 6 feet above old grade through 39th St. station with its permanent run-off northward to 38th St. and with a temporary run-off southward toward 40th St. Column extensions north of the station were riveted in place, the structure was landed and blocking removed, except at the station where the structure was left on its blocking to await future reconstruction at that point. The structure for the extent of the temporary run-off was also left on its blocking to be used in a further raise at a later stage of the work.

While this work was going on, new foundations were being put in for the change of line at the east curve. The existing structure at the east curves was now jacked-up to the grade established for the reconstructed line at that point, the elevation beginning at a point about 300 feet south of the south end of the old curvature, extending, at the established grade, past the platforms of Indiana Ave. station and ending, at this stage, in a temporary incline west of the station. The maximum raise—namely: opposite the station platform was 4.7 feet.

Following the jacking-up, column extensions were riveted to the columns that were to remain in the work and that portion of the structure that was to be replaced with new structure was left on its blocking.

Meanwhile the new Third Track structure, on the east side of the old, from 43rd St. to the south end of the new curve was erected. Next all that portion of the new east curve that could be put up without interference with the old structure and with the operation of trains was erected on its new foundations, and, at the same time, track was being laid on the new Third Track structure between 43rd St. and the south end of the new curve.

The new south bound track from the east end of the platform at Indiana Ave. station around over the new structure was also laid ready for a connection.

Up to this point, traffic on the two old tracks had not been disturbed, but reconstruction had now reached a point when traffic must be diverted in order to continue the work. Accordingly single-track service was now installed over the old north bound track between crossover No. 4, just east of the station and crossover No. 8, just south of bent No. 537, (Fig. A large plate), where new and old construction were to be joined—south bound trains running in the face of north bound between these crossovers.

During this movement of trains, the old south bound track and structure around the curve was torn out and the new south bound structure was connected with the old south bound, at bent No. 537, and new south bound track was laid to a connection with the old south bound at that point; and crossover No. 5 (Fig. B) was laid.

Two-track service was now resumed around the curve, north bound traffic continuing over old north bound track and south bound over new south bound, using crossover No. 5 as shown.

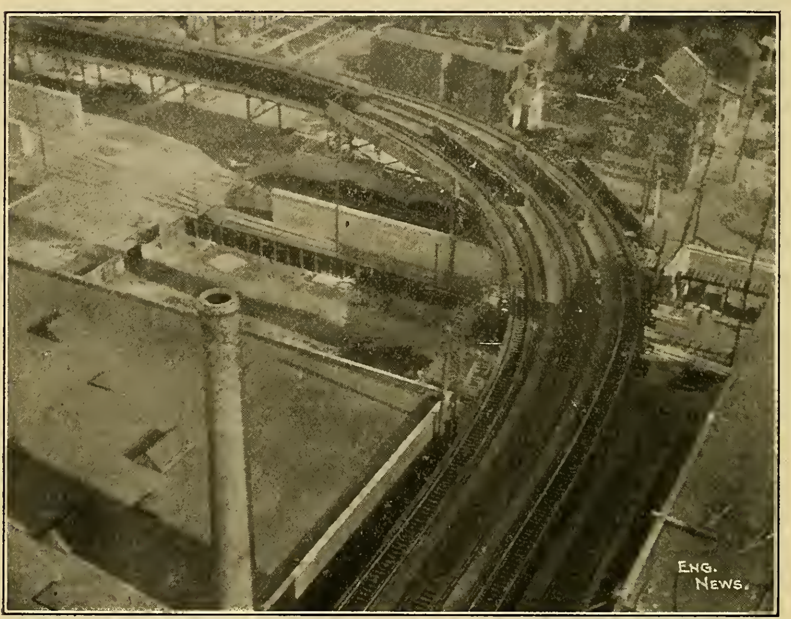
During this movement of trains crossovers No. 4 and No. 8 (shown in Fig. A) were interchanged right to left and left to right (as shown in Fig. C), and single-track movement over new south bound track around the curve was installed, leaving free the old track and structure between these crossovers.

The remainder of the old structure around the curve was now torn out and the new structure for the middle and north bound tracks was erected, and the track laid around the curve, except a gap between S and T (Fig. C) which could not be completed until traffic was completed between S and T (Fig. C), and through girders of the the station was now laid; crossover No. 4 (Fig. C.) was abandoned and the present single-track movement was extended westward through the station on the south bound track, using crossovers Nos. 10, 5 and 8 (Fig. D). During this movement, the structure and track was completed between S and T (Fig. C) and through girders of the

40th street, near west curve, with temporary trestle.

north bound track at the station span were erected, the old track through the station was torn up and the new track laid.

Continuous double-track service was now again resumed (as shown in Fig. E), the middle and north bound tracks to 43rd St. being used. During this train movement the right-hand crossover just west of the station was changed to a left, and the crossover just east of the station connecting the middle and new south bound tracks was taken out, the situation being as shown in Fig. F.

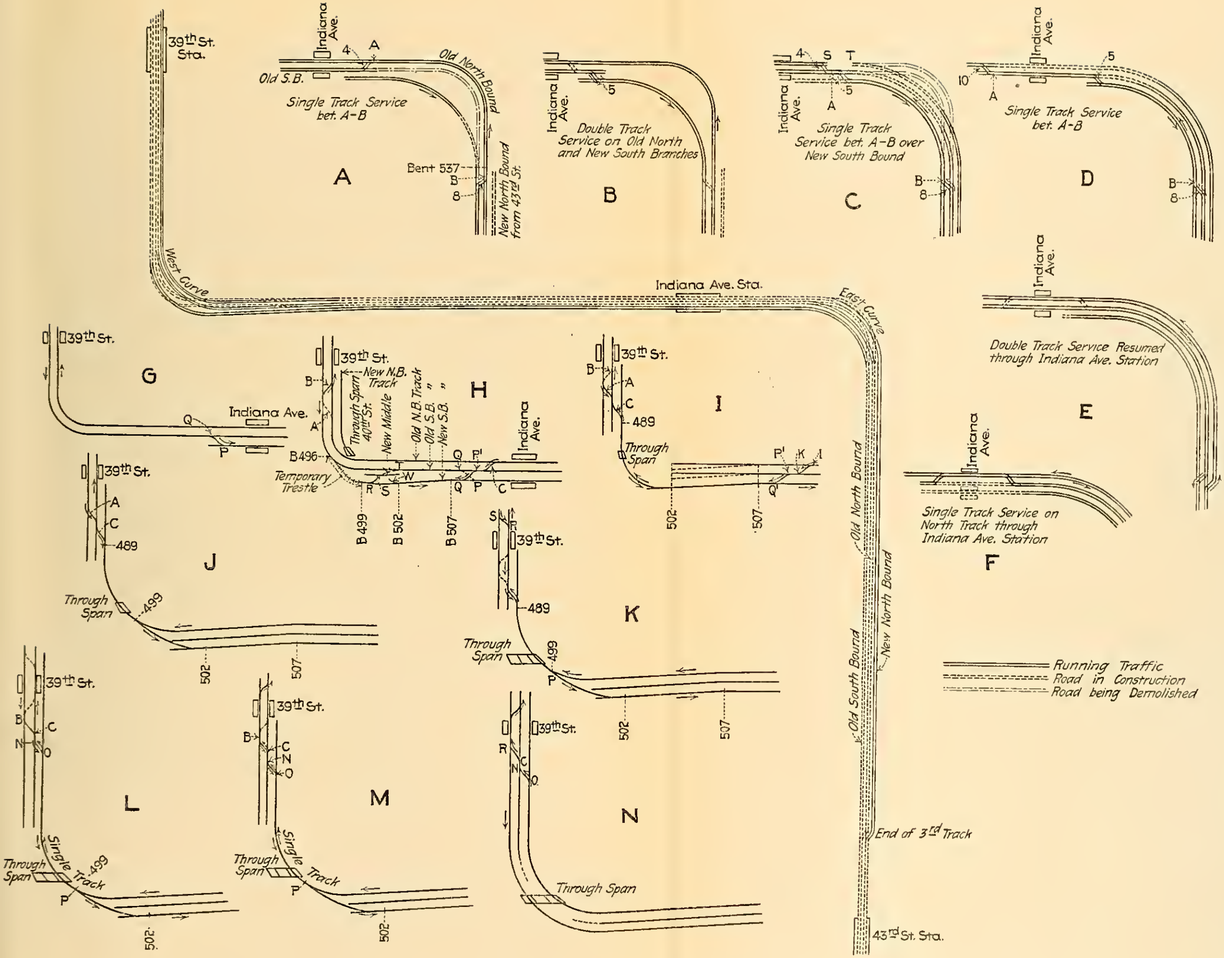


West curve at 40th street, finished structure, looking southeast.

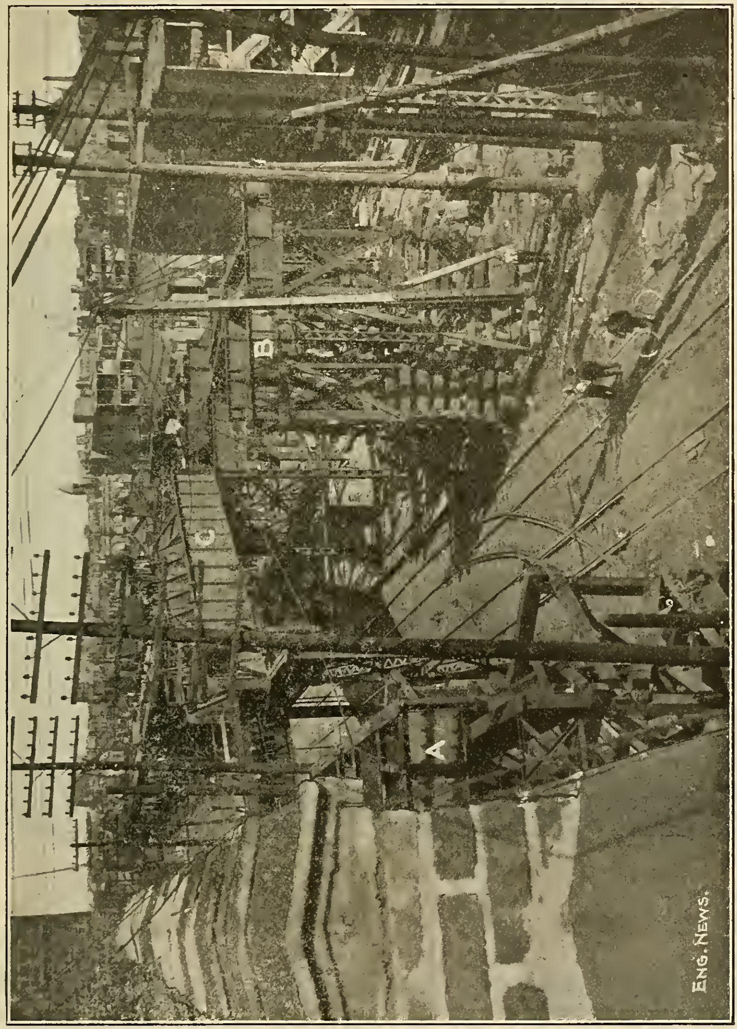
Single-track movement on the north bound track through the station was now installed over these crossovers. During this movement, the structure for the new south bound track was erected past the station, the south platform was jacked-over to its new position (Fig. F), the remaining through girders at the station span were erected, and the new south track was laid through the station.

While the above mentioned work was in progress, a temporary station had been erected at Prairie Ave. with temporary stairs leading up to the east end of the platforms. Traffic had been diverted to this and the old station at Indiana Ave. had been wrecked. On the site thus cleared, the new station was now erected on the steel work suspended from the structure at the through span.

Also, while these changes were in progress, the jacking-up of the


39th St. Sta.
West Curve
Indiana Ave. Sta.
East Curve
Old North Bound
Old South Bound
New North Bound
End of 3rd Track
43rd St. Sta.
A
Indiana Ave.
4
A
Old S.B.
Old North Bound
Single Track Service bet. A-B
Bent 537
B
8
New North Bound from 43rd St.
B
Indiana Ave.
5
Double Track Service on Old North and New South Branches
C
4
S
T
Indiana Ave.
A
5
Single Track Service bet. A-B over New South Bound
B
8
D
Indiana Ave.
5
10
A
Single Track Service bet. A-B
B
8
E
Indiana Ave.
Double Track Service Resumed through Indiana Ave. Station
F
Indiana Ave.
Single Track Service on North Track through Indiana Ave. Station
G
39th St.
Q
Indiana Ave.
P
H
39th St.
New N.B. Track
B
A
Through Span 40th St.
New Middle
Old N.B. Track
Old S.B. "
New S.B. "
B496
Temporary Trestle
R
S
W
Q
P'
Q
P
C
Indiana Ave.
B 499
B 502
B 507
I
39th St.
B
A
C
489
Through Span
P'
K
I
Q'
502
507
J
39th St.
A
C
489
Through Span
499
502
507
K
S
R
39th St.
489
Through Span
499
P
502
507
L
39th St.
B
C
N
O
Single Track
Through Span
499
P
502
M
39th St.
B
C
N
O
Single Track
Through Span
P
502
N
39th St.
R
C
N
O
Through Span
Running Traffic
Road in Construction
Road being Demolished

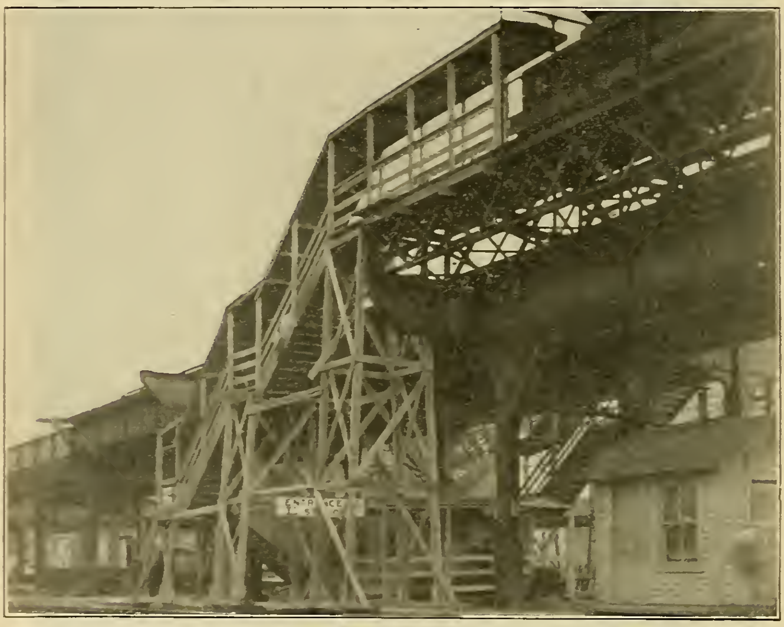
old structure from Indiana Ave. to 39th St. had been carried steadily forward to completion.



New construction at west curve at 40th street.

All structural changes and additions from Indiana Ave. station southward, being now complete, final two-track service on the outer tracks from a point just west of Indiana Ave. to 43rd St. was now installed, the situation at this state being as shown in Fig. G, which shows the new track and structure completed to the point mentioned, with the crossover used in this service in position The arrows in the figure indicate the train movements.

The erection of the new Third Track structure had now (July, 1905) been carried westward to bent No. 499 (shown on Fig. H), also the new middle track structure between bents Nos. 499 and 502 was erected. Also a temporary trestle outside of the existing structure from bent No. 496 to No. 499 (Fig. H) was erected to connect the old and new south bound tracks for temporary purposes of construction. Meanwhile tracklaying had been kept close up with the erection, and by Sunday, July 23rd, track was all laid over the new south bound track and temporary trestle ready for a connection at bent No. 496.



Temporary arrangement at station, 40th street and Prairie avenue.

To make this connection and at the same time to disconnect crossover Q.P. (Fig. G), Sunday was chosen, as comparatively few trains are run on that day. Accordingly in the forenoon of Sunday, track connection was made at the point mentioned and crossover Q.P. was removed from the south bound track. While this was being done all south bound trains were diverted to the north bound track at crossover A (Fig. H) and switched back to south bound track at 43rd St.

On the completion of this work, two-track service was immediately resumed, south bound trains now being run via temporary trestle and new south bound track southward.

Next, the middle track now being clear, by the use of the two outer tracks a portion of same west of T, near bent No. 502, is swung over and connected with switch R.S. Single-track movement around the west curve is now installed, north bound trains passing via crossover C, T.S.R., the temporary trestle, and crossover B to their proper platform at 39th St. station; and south bound trains continuing via temporary trestle and new south bound track to Indiana Ave. station and southward. This movement leaves all the east portion of the old structure of the curve clear for tearing out and rebuilding.

During this single-track movement the following work was done: Completed erection of new east track structure from curve at 40th St. to south end of station platform at 39th St., (as shown on Fig. H), and erected through girders for new north bound track over Chicago Juction Railway at 40th St. Meanwhile all free old structure between bents No. 499 and No. 502 was torn down and new structure was erected in its place. Right-hand crossover Q.P. was changed to left, Q′.P′. on same location. New east track between 39th St. and bent No. 499, including that portion through the east through girder span, together with all other track that it was possible to lay was laid.

In order to get at the balance of the old curve and to erect the new, it now became necessary to abandon the crossover R.S.T. (Fig. H). This was effected by extending the single-track service to Q′.P′. just east of bent No. 507; R.S.T. was now taken out, and turnout W, just west of bent No. 502, was laid to a connection with the new north bound or east track, just south of the through girder span, with a switch inserted in line for the future or completed north bound track.

The work had now advanced to a point where another diversion of traffic was necessary in order to vacate the balance of the old structure at the curve. Accordingly on August 11, 1905, single-track movement was installed as shown (Fig. I).—south bound trains coming onto the single track via A and C, and north bound via I.K.P′.Q . This movement, as shown on figure, left the old two-track structure between bents No. 502 and No. 507 out of service and ready to be jacked-over to its new position parallel with the new Third Track and to a connection with the new three-track structure west of bent No. 502.

This work was now, accordingly, done, the structure having been left on its standard blocking on rollers provided for the purpose. The balance of the old curve structure was now torn out, the remaining through girders over the Chicago Junction Railway were erected as well as the remainder of the structure south of the through girder span.

The new north bound track was now laid westward on its permanent location to a connection with its corresponding track at bent No. 499, at the switch previously mentioned (Fig. J). On the completion of this connection single-track service was shortened up to this point from the east, greatly facilitating the handling of trains.

A left-hand crossover was now installed between the two old tracks just north of 39th St. station, for use during the reconstruction of that station. Single-track movement over east track at the station was now installed, extending from R to P, Fig. K; south bound coming on at S.R. and re-entering south bound track at P. The old west track was now torn up through past the station platforms; new through girders for the west track at the station span were erected, and new south bound track, south from the station was laid.

Double-track service through the station was now resumed, the single-track service being now limited to C.O.P., Fig. L.

During this movement the crossover north of the station was changed from left to right, whereupon single-track movement was diverted to south bound track at the station and combined with the continued single-track movement across 40th St., the single track movement now extending from V over crossovers B., C. and N.O. to P, Fig. M.

During this movement the new Third Track structure is erected northward past the station; through girders are erected for the middle and east tracks at the station span; and the east platform is jacked-over to its new position for the third track.

Meanwhile the south bound track has been laid to a connection with its corresponding track on 40th St., and now double-track service is immediately installed south of 39th St. on the two outer tracks (as shown in Fig. N), thus shortening the single-track service to the space between V and B at the station platform.

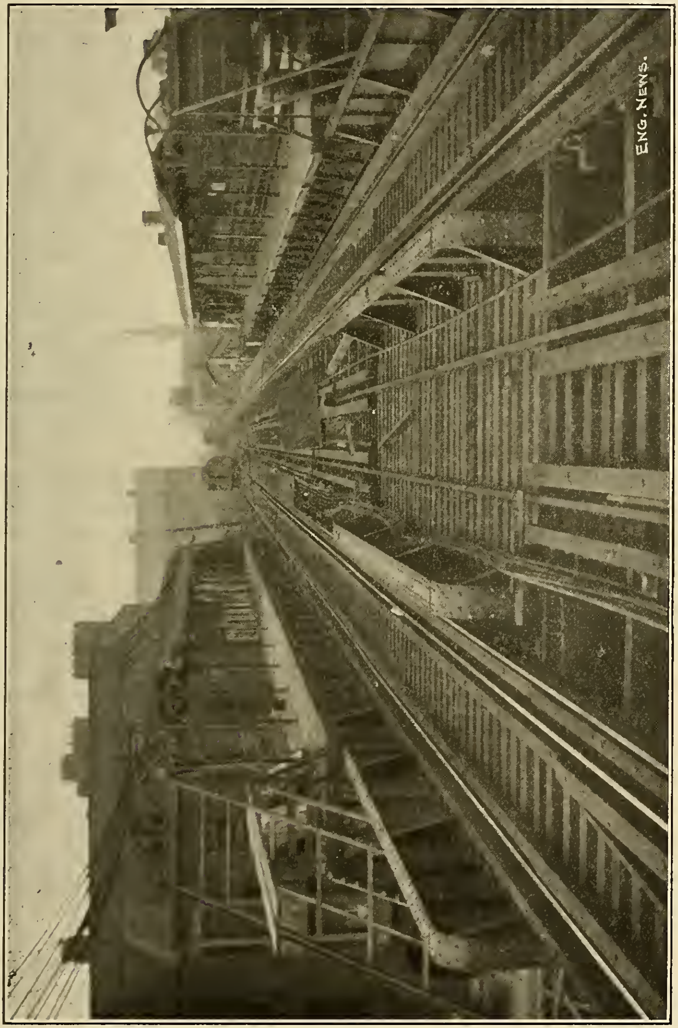
The new north bound track is now laid past the station to a connection with the corresponding track that has already been laid between 39th and 35th St. stations; and double-track service is now installed, thus making the operation of the third track continuous from 43rd St. to 35th St., and leaving the middle track between these points free for future express service.

The entire work of adding the third track, reconstructing the curves, raising the old structure, etc., from 38th to 43rd Sts., covered a period of about eight months—namely, from about February 1 to September 27, 1905.

This work being carried on as it was under traffic, involved many trying and difficult problems both of design and execution. Its essential features were so interrelated, so interdependent that no single phase of the work could be treated independently, but only with due regard to all its relations, and everything had to be carried out, in the field as in its design, as a part of a complicated whole.

As in the design and execution, so in a description, once commenced, there seemed to be no place for a pause until the end was reached. I have, therefore, even at the risk of tediousness and prolixity in detail, enumerated at some length all the essential details of this important and difficult piece of work—namely, from 38th to 43rd Sts.

I would add that in this as in all the rest of the work—adding the third track and the reconstruction of the old structure, the original plans and designs provided were not deviated from in any essential detail; and during the whole course of the work there was no accident and no serious inconvenience to the traveling public.



Typical view of reconstructed tracks at stations.

In the earlier stages of the work, the question was often asked whether the waving grade adopted was to secure an advantage in the handling of trains, and a wish has been expressed that this paper would deal with this feature of the work, to the end that the extent of this advantage, if any, might be brought out.

In answer to this, I would state that the grades as they stand today were established solely to secure the necessary headroom underneath; and that, whatever resulting advantage may have accrued, (which advantage would be confined exclusively to the movement of local trains) is merely incidental to the main consideration.

The amount of this advantage has not been, and probably cannot be, computed by any general mathematical formula, due to the existence of so many varying and limiting conditions such as,—the length of the level stretch on which the train is stopped, the varying position of the train on the level stretch, the length of the train, etc.

We know, of course, that the resistance due to a grade of 1% is 20 lbs. per ton of 2000 lbs., which resistance aids in the stopping of the train as it approaches the station and which also aids in the acquisition of maximum velocity on the 1% run-off when same is reached.

The initial current required to start the train on level track is a readily determinable quantity. If the head of the train at starting is at the beginning of the run-off, the advantage at starting is zero, and gradually increasing toward the 20 lbs. per ton till the entire train comes on to the incline, when the maximum saving of current is attained.

As is usually he case, however, the train stops at some intermediate point on the level stretch, in which event no saving of power is available in starting, such saving coming into play only after the train has acquired some velocity.

All these varying conditions are enumerated to show that any general formula to fit all cases would be impossible, or, at least, difficult to secure. This question, however, is an interesting one; and it is to be hoped that a discussion of this paper may bring out, as one of its features, some ideas that may tend toward a general solution of the problem if such is attainable.

DISCUSSION.

Mr. W. B. Storey, Jr., M.W.S.E.: This paper has been an extremely interesting one to me, and Mr. Darling has indicatel very clearly the difficulties that engineers have to meet in work of this character. I think the thanks of the Society are due the author for the very efficient way in which he has presented the subject to us.

Mr. Darling: In this connection I wish to say that I regret that I could not have furnished better material for illustrating the work on 40th Street.

Mr. J. C. Fruit: I might call attention to the difficulty experienced in the field in tying the new structure to the old. This tying together system, consisting of cross frames and laterals, was designed from the drawings of the old structures in conjunction with drawings for the new. When the work had been fabricated and erection commenced it was found that the old structure had settled considerably out of line and that tying cross frames and laterals would not fit in the majority of the spans, necessitating new members for these spans.

Mr. Darling: Theoretically, the old structure was supposed to have some sort of standard and I presume it did, but as a matter of fact little irregularities had developed with the years, and it required special devices for about every span. This necessitated the connecting work to be furnished in blank and the drilling to be done to fit.

Mr. Storey: Was this work, as well as the work on the track and that which you have shown us in the way of changing switches, etc., all performed by contract?

Mr. Darling: Yes, all the work was done by contract,—foundation work, track work, and everything of the kind. The contractor did the switch work on a percentage basis.

Mr. Storey: In this connection I will say that most of the steam railroad companies, in the rebuilding of bridges, do not use contract work. The nature of that kind of work has seemed to necessitate the organization of their own gangs. Most of the western railroad companies have their own gangs working month after month and year after year taking down old bridges and putting in new ones.

Mr. Darling: I ought to say, in justice to contractors, that our experience was a happy one all through the work. The contractors worked under great difficulties in connection with the train service, and they did the work just as we wished to have it done. We had no trouble at all in that respect, nor on the percentage basis.

Mr. Storey: I suppose the work on the percentage basis was done at so much per pound?

Mr. Darling: Yes, you are correct.

Mr. Fruit: It might be interesting for me to state that during the work of construction the structure had to be supported for some eight months on wood blocking, on account of labor troubles.

Mr. Wm. B. Jackson, M.W.S.E.: What led to the increase in size of the bearings of the foundations?

Mr. Darling: In adding the third track it was found that there was additional weight brought on to the old foundations, so we renewed the old foundations. We took out 230 old foundations and put in new ones generally 9 ft. by 9 ft. In most cases the old foundations were renewed on the side adjacent to the new 3rd track structure.

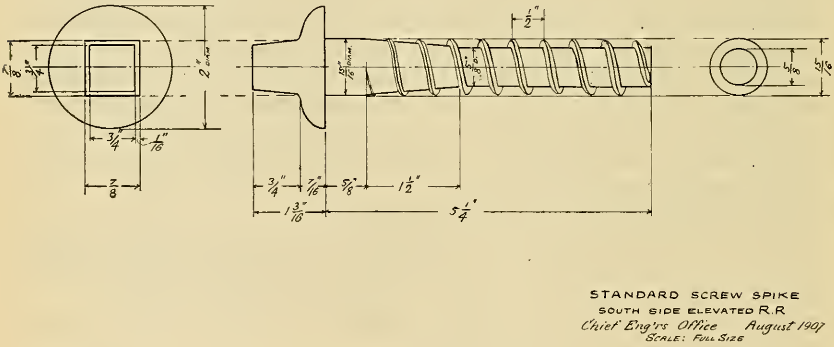
Mr. A. Reichmann, M.W.S.E., (Chairman): There is one feature that was not brought out very clearly in the paper, and that is, that the old structure was very strongly braced all along the line from the new structure. That added quite a little to the work.

Mr. Storey: Were any special precautions taken relative to protection from danger incident to the third rail, while the work was going on? Where there any accidents to the workmen due to coming in contact with the third rail?

Mr. Darling: No precautions were taken, and very few accidents occurred. The workmen simply looked out for themselves. Occasionally one would receive a little jolt, but I do not recall that any workman was killed from that cause.

Mr. Storey: I would point out that this is certainly a remarkable example of what can be done in electric railway construction, taking into consideration that the service was continued with very little interruption. One of the problems that presents itself is the danger to the workmen in handling track, and I can hardly conceive of a more complex case, where the men were thrown close to the third rail in all of the work they had to do, than in the work which has been shown us this evening, and a record like that deserves special attention.

Mr. Darling: It does seem remarkable that the work could be done in such close proximity to the third rail without more accidents, especially in view of the large number of trains which were in operation continuously. My experience has been, however, that where danger is ever present, one's mind is continually charged with the thought of danger, causing him to be alert all the time, and accidents are likely to be reasonably rare in such cases.



Screwspike used in new work.

Mr. Reichmann: I would ask how successful the screw spikes for securing the rails have been on this work?

Mr. Darling: It is eminently successful so far, and I see no reason why it shouldn't continue to be satisfactory in the future. However, time will tell what may develop when the track has to be renewed. I know of rails having worn out and renewals having been made, but have heard no expression of dissatisfaction or of any insurmountable difficulty in withdrawing the spike. It certainly holds the rail in place in good shape, does not split the tie, and does not destroy the wood. I think it will prove to be a very satisfactory spike.

Mr. Story: I would ask Mr. Darling what the size of the tie plate was, and also what was the style of plate?

Mr. Darling: The tie plate is flat with a little flange fitting up against one edge of the rail, anl the spike holes come diagonally on the tie. I will ask Mr. Ralls to state the size of the tie plate, as I have forgotten it.

Mr. M. S. Ralls, M.W.S.E.: The size of the tie plate is ⅜ in. in thickness, 6 in. wide and 8 in. long, with staggered spike holes, these being 15-16 in. in diameter and spaced between centers 5⅞ in. It has a shoulder or rib on one side, which sets up firmly against the flange of the track rail, but there is no rib on the bottom of the tie plate, it rests flat on the cross-tie. The spike holes are staggered, the staggered distance being 3¼ in. center to center. This is the style of tie plate used on tangent track. On curved track, where a steel guard rail is required, the tie plates vary in length, according to the radius of the curve. Those used on the curves are numbered 1, 2, 3, 4 and 5:

No. 1 is 10⅛ in. between centers of spike holes.
No. 2 is 10¼ in. between centers of spike holes.
No. 3 is 10⅜ in. between centers of spike holes.
No. 4 is 10½ in. between centers of spike holes.
No. 5 is 10⅝ in. between centers of spike holes.
No. 1 gives 1¾ in. flange way.
No. 2 gives 1⅞ in. flange way.
No. 3 gives 2 in. flange way.
No. 4 gives 2⅛ in. flange way.
No. 5 gives 2¼ in flange way.

Mr. Story: In this connection I might say that the tie plate is creating a good deal of attention, and the rib spoken of is, as a rule, put on the outside of the track.

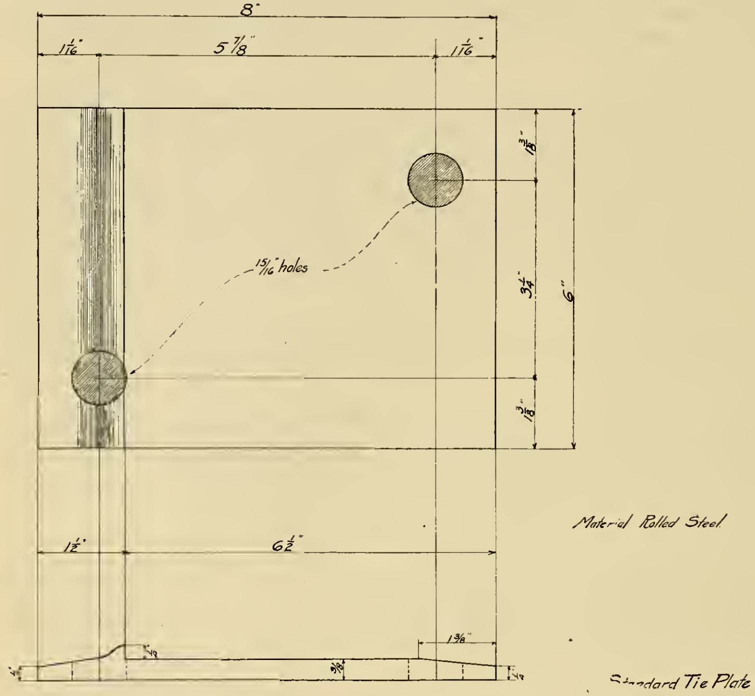
Mr. Darling: I think it is understood that our tie plates are flat on the bottom, and that there is no rib to cut into the tie.

Mr. J. H. Warder, M.W.S.E.: Would not the cost of the screw spikes be about double that of the ordinary driven type?

Mr. Darling: I am not certain what they do cost, but I think they cost at least that much more than the ordinary spike. The cost of laying track is a little more with the screw spike.

A Visitor: What is the method of driving the screw spike, and about how long does it take?

Mr. M. S. Ralls: With a full force of men on double track work, 20 screw spikes per minute can be put in. The holes are bored by mechanical power, requiring two men to operate the boring machines, one engineer followed up with two men starting and setting spikes, and they followed up with two crank wrenches requiring four men to operate them, and one man to distribute the spikes. With this force of men, and everything working in good condition, 20 spikes per minute can be put in. Compressed air was used as power for drilling the holes.



Tie plate under rails.

Mr. **E. E. R.** ***Tratman,*** M.W.S.E.: The wave-line grade system, with grades of 1.66 per cent. at each station, was proposed some 25 years ago for an underground railway in London (England). The line was to be operated by storage battery or compressed air locomotives. I was engaged upon the plans at one time. The line was never built, but was on the route of the present electric tube line of the Central London Ry. I would like to ask how the trains were controlled in passing over the single-track sections of the elevated railway. This is an important matter with such a frequent service of trains.

Mr. Darling: The trains are controlled by a flagman at each end on tangents and around curves one in the middle. They signal one to the other so the trains cannot come on without the consent of the men on watch.

Mr. J. G. Spielman, M.W.S.E.: In regard to the size of foundations, as I understand the construction, the new column is braced to the old structure in such a way that settlement would throw considerable stress on the bracing, and for that reason I think it is a good thing that the foundations were made larger than usual. The old columns had settled a certain amount and would not be likely to settle any more. Naturally a new foundation would settle a little after putting it into use, and if it were made no larger than the old one, it would be fair to assume that it would settle as much as the old one, and this larger foundation would counteract the effect of settling. I understand that in your cross-girder section you put in foundations all of the same size; that would take care of that settling; otherwise your girder might be settling on one point only.

Mr. Darling: I would like to hear from someone on the subject of waving grade. I think I brought the matter out so that it was understood that the train stops at a station on a level grade, and usually it is, we will say, 40 or 50 ft. from the front end of the train to where the grade begins to drop off. It is easy enough when the train is entirely on the 1 per cent. grade, to tell how much benefit is derived by the grade as an aid to starting. The position of the train, of course, precludes any incidental benefit while the train is starting, but the advantage, due to the fall of 1 per cent. grade, does come in before the train gets its full speed. I was hoping there might be someone here who, perhaps with a due amount of thought, could give some formula that would lend itself to a solution of a general proposition of this kind.

Mr. Story: So far as steam roads are concerned, any aid in starting in getting the train up to speed is a great advantage, and a grade of that kind would be an aid. Take a train traveling at 60 miles an hour,—it begins to stop at a distance of one-half to three-quarters of a mile, and it takes it three miles to regain its regular speed. A down grade would very materially assist in getting up the speed.

A Visitor: How are the points located on the curve, in laying out the work?

Mr. Darling: They are located usually from the base line outside of the curve—from a straight line. Sometimes the situation is such that they can be located directly from the center, but the usual procedure is to lay off the base line and figure the location at the column points at right angles from the base line and figure out the distance. It is necessary sometimes to establish a sub-base line.

ELECTRIC EQUIPMENT OF SIEAM AND GASOLINE AUTOMOBILES

MR. F. R. BABCOCK.

Read before the Electrical Section, May 8, 1908.

Since the earliest days of autobobile history, electricity has played an important part in the design and operation of all machines, which depend for motive power on some form of explosion or internal combustion engine. It is only within comparatively recent years, however, that it has found any purpose, save that of ignition. As might be expected, the vast increase in the application of electricity to other lines of work has stimulated its use in the automobile field until at the present day, it is taking the place of acetylene or kerosene for illumination, hand and exhaust operated horns for signalling, gears and friction devices for speed changing, and serving a host of minor purposes. It is my purpose in this paper to give a brief account of some of the various devices, combinations and arrangements, which have been used in the application of electricity to the various purposes mentioned.

The first purpose for which electricity was employed in the automobile was for ignition and this is still the most important of its applications. Two methods of igniting the charge are in general use, known respectively as the high tension or jump spark and the low tension or make and break spark. As the names imply, the former depends on a discharge of electricity at high tension between fixed electrodes inside the cylinder, while the latter uses a low tension circuit, in which is included a coil of wire having considerable self-induction, the circuit being made and broken by moving electrodes within the cylinder. These two schemes modified in detail to suit the ideas of individual designers are practically in universal use today. We will consider first, these two systems as a whole and later take up the source of electrical energy, which may be used for either one.

HIGH TENSION SYSTEM.

This consists in its elements of an induction coil for raising the voltage of a battery or generator to the potential required to jump a gap of 1-32 to 1-16 of an inch under pressure of 50 to 80 pounds per square inch. The spark plug, battery or generator, and timer complete the essential elements of the system. In detail, this simple apparatus may take one of a number of different forms, dependent upon the construction of the engine, the source of current, etc., and we will discuss briefly the principle arrangements in use.

On a single cylinder engine, the system approaches the ideal one in simplicity. As the number of cylinders is increased, the apparatus may be multiplied, making practically an individual system for each cylinder, or a single coil may be used and suitable distributing devices employed to conduct the high tension current to the proper cylinder at the proper time. Further variation may be obtained by of storing or holding back the flood waters. This has some bearing upon the reputation of the engineers of the plants. In one particular case, an engineer was severely criticised because a plant did not have sufficient water supply to develop its rated capacity at all times. It seems not unlikely that a study of the run-off data and other records may have warranted the assumption of a steady supply, but that deforestation on the drainage area may have so changed the conditions as to produce alternations of flood and low water in the stream. Under such conditions additional works may be necessary, in the form of reservoirs to hold back the flood waters for use during low-water periods.

SPECIAL CONCRETE STRUCTURES IN THE HUDSON RIVER TUNNELS

W. M. TORRANCE, M.W.S.E.

Read April 1, 1908.

A very important part of the final subway railroad system of the Metropolitan district of New York is that now under construction by the Hudson Companies.

A plan of this system as at present authorized and under way is shown in Fig. 1. The portion from the Hoboken terminal to Nineteenth street and Sixth avenue, New York City, has been completed and was opened with formal ceremonies, February 25th, of the present year. As shown by this drawing, there are two sets of double tunnels under the river, which are connected on the New Jersey side. The upper set reaches from the foot of Fifteenth street, Jersey City, to the foot of Morton street, New York City and thence up Christopher street and Sixth avenue to stations corresponding with, and almost directly underneath; those of the Sixth avenue and Ninth avenue Manhattan elevated railroads. A branch extends to Astor Place and has a passage-way connection with the Astor Place station of the New York Subway. The lower set of tunnels makes a loop on the New York side at Church street between Cortlandt and Fulton streets, where twin terminal buildings extend from one to two stories below the subway tunnel track level (80 or more feet below the street) to twenty-two stories above the street.

This tunnel system was started in 1874, a shaft being sunk at the foot of Fifteenth street, Jersey City, in that year. Tunnel construction from this shaft eastward and from a shaft at the foot of Morton street, New York City, westward was carried on during the years 1881 and 1883, when cessation of work was caused by a lack of funds. The work built at that time had brick walls about thirty inches thick with a thin iron casing, and was constructed by the "pilot tunnel" method—a 6 foot pilot being used. A total of about 2,000 feet of the northern tunnel and 600 feet of the southern tunnel was finished at that time from the New Jersey shaft, only a small amount of work having been done from the New York end.

In 1890 the construction work was continued by an English company, with S. Pearson & Sons, contractors; this time by use of the hydraulic power shield method, using cast iron rings. This was the first large tunnel on which this method of construction was adopted. In 1891 the work was again abandoned on account of lack of funds, after the northern tunnel had been extended 1,700 feet further toward New York.

In 1900, Mr. Charles M. Jacobs, an English engineer of wide experience in difficult tunnel work, made a careful survey and detail examination of the work, and in 1902, the present company (Hudson

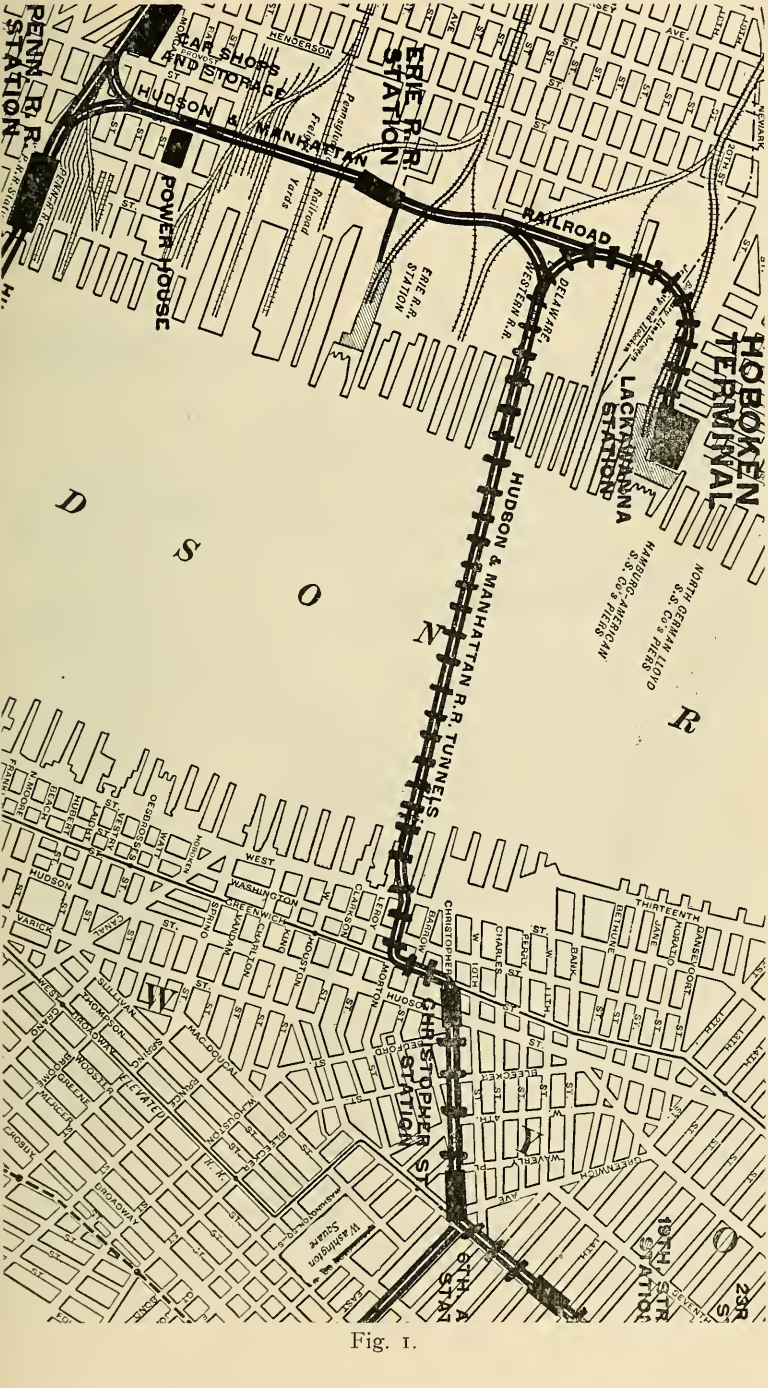

PENN. R.R. STATION
CAR SHOPS AND STORAGE
HUDSON & MANHATTAN RAILROAD
POWER HOUSE
Pennsylvania Railroad Freight Yards
ERIE R.R. STATION
ERIE R.R. STATION
DELAWARE, LACKAWANNA & WESTERN R.R.
LACKAWANNA STATION
HOBOKEN TERMINAL
HUDSON & MANHATTAN R.R. TUNNELS
D S O N R
NORTH GERMAN LLOYD S.S. Co's PIERS
HAMBURG-AMERICAN S.S. Co's PIERS
HENDERSON
NEWARK
20TH ST.
WEST
WASHINGTON
GREENWICH
HUDSON
VARICK
CANAL
THIRTEENTH
CHRISTOPHER ST. STATION
BLEECKER
WAVERLY PL
GREENWICH AVE
Washington Square
WEST BROADWAY
ELEVATED
6TH AV STA
19TH STR STATION
23R S

Fig. 1.

Companies), with Mr. Jacobs as Chief Engineer, began operations. They found the shield, abandoned at the heading in 1891, in good condition and completed the tunnel to Morton street, New York, on March 11, 1904, using the old shield.

On September 22, 1905, the present company also completed the southern tunnel, this bore being from end to end a circular, shield-driven, cast iron ring tunnel; the 600 feet of brick tunnel built in 1881-1883 having been abandoned.

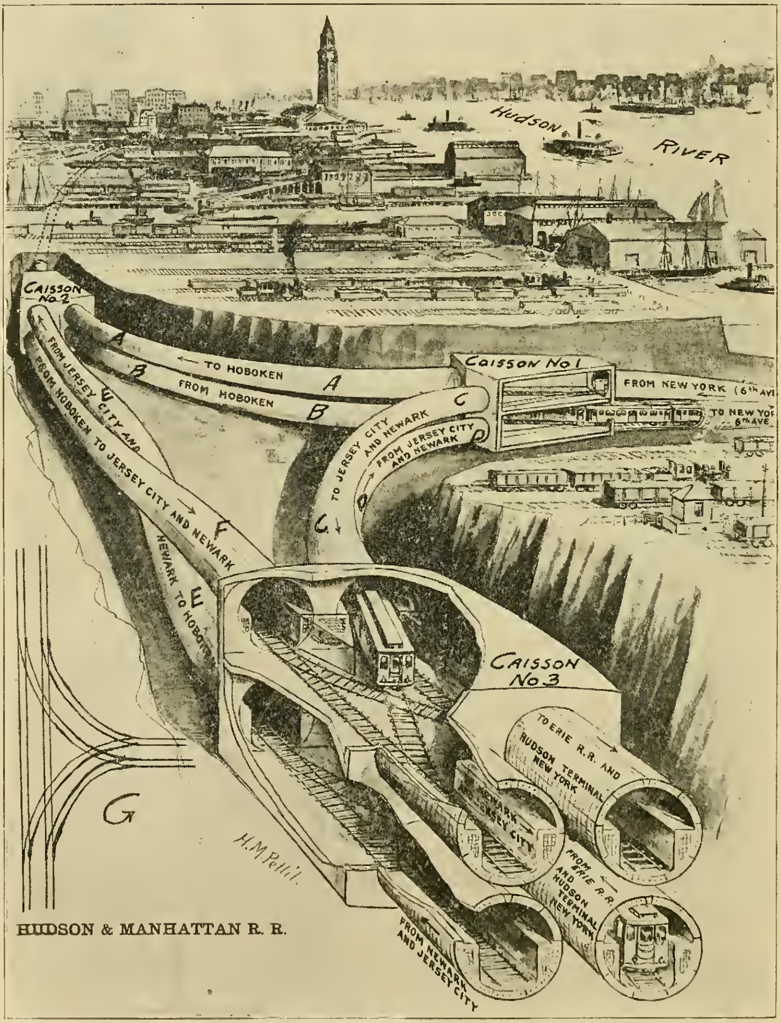

Hudson
River
Caisson No 2
Caisson No 1
Caisson No 3
← TO HOBOKEN A
FROM HOBOKEN B
A
B
FROM NEW YORK (6th AV
TO NEW YORK 6th AVE.
C
TO JERSEY CITY AND NEWARK
FROM JERSEY CITY AND NEWARK
C
D
FROM JERSEY CITY AND
FROM HOBOKEN TO JERSEY CITY AND NEWARK
F
NEWARK TO HOBOKEN
E
TO ERIE R.R. AND HUDSON TERMINAL NEW YORK
FROM ERIE R.R. AND HUDSON TERMINAL NEW YORK
NEWARK JERSEY CITY
FROM NEWARK AND JERSEY CITY
G
H.M.Pettit
HUDSON & MANHATTAN R. R.

Fig. 2.

Fig. 2, is from a free hand sketch showing in perspective a portion of the tunnel system on the New Jersey side. The tunnel marked "A" contains the west-bound track to Hoboken, and "B" the east-bound track from Hoboken. The tunnels marked "C" and "D," "E" and "F" will contain tracks leading respectively from and towards Jersey City. In order to obtain the proper directions it was necessary to cross the tunnels "E" and "F" vertically.

It was obvious to the engineers that it would not be economical to construct the tunnels at the turnouts by means of a shield. It was necessary to have a section of tunnel which would enlarge from the ordinary circular tunnel at one end to a sufficient width at the other for two such tunnels to be driven forth. Many studies were made to determine the best means of accomplishing this end, the final decision being to construct such a piece of tunnel on the surface of the ground and sink it by means of a pneumatic caisson excavation.

In order to avoid grade crossings in this double tracked wye, such as would occur if the tracks were made parallel to each other at grade, (see the sketch "G" of an ordinary double track wye. Fig. 2), the grades of the two tunnels were made at different levels, and in order to save cost in the construction of the caissons, they were built double decked, the enlarging tunnel for one system of tracks being directly over that for the other, thus making the floor of the one the roof of the other. Otherwise it would have been necessary to have separate caissons for each level.

Structural steel caissons were designed for this purpose, but found impracticable because of cost and the length of time necessary for fabrication and erection. Further studies were made along two lines: First, to see if the design could not be simplified by the introduction of knee braces and a reduction in depth of girder by allowing at least a portion of the compression stresses to be assumed by the concrete filling; and second, by constructing the caisson wholly of reinforced concrete with practically all the compression stresses taken by the concrete. The latter plan was adopted, the principal reasons for the decision being:

First: The saving of time due to the fact that concrete materials and reinforcing iron could be obtained promptly, thus allowing the work to start at once.

Second: Because it was found that the amount of concrete required in the structural steel caisson to overcome the buoyancy due to the use of compressed air and to skin friction was fully as great as the total amount necessary in the reinforced concrete design.

Third: A considerable saving in cost, estimated at $100,000 per caisson, chiefly because of the saving in steel. In Fig. 3, is shown a plan of Caisson No. 1, somewhat in detail. The calculation showed a necessary thickness of walls of three feet, but three feet more was added for the electrical conduits. This extra thickness was added at the outset in the middle portion in order to increase the weight.

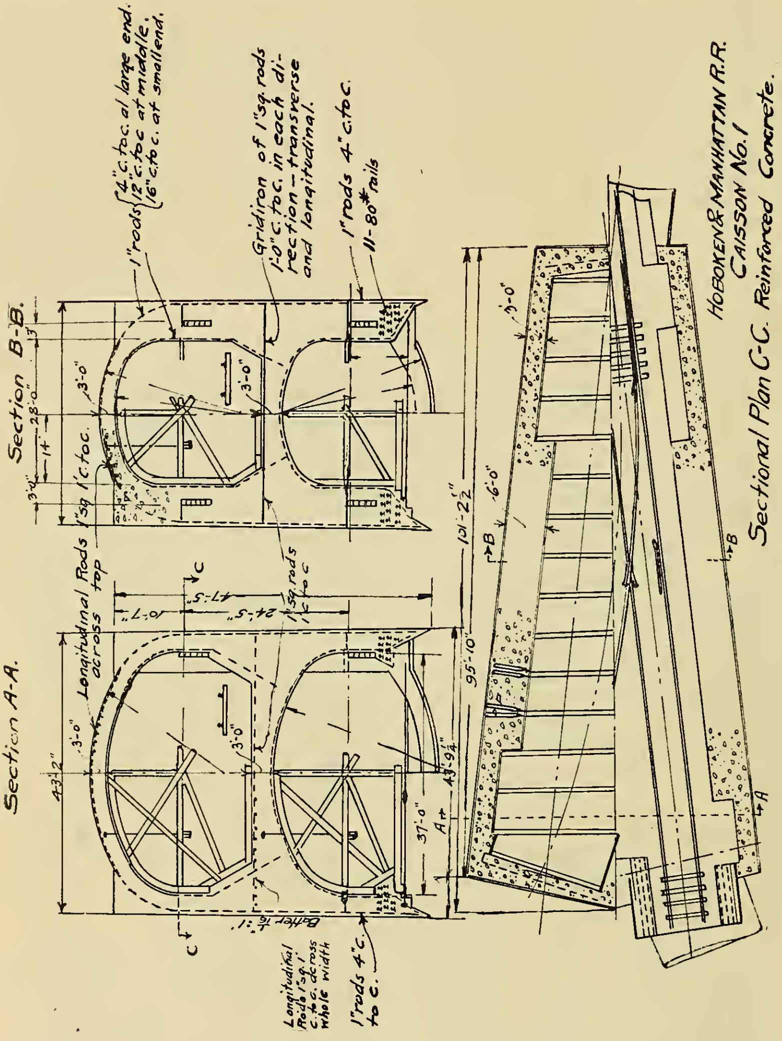

Section A-A.
Section B-B.
1" rods {4" c. to c. at large end. 12" c. to c. at middle. 16" c. to c. at small end.
Gridiron of 1" sq. rods 1'-0" c. to c. in each direction—transverse and longitudinal.
1" rods 4" c. to c.
11-80# rails
Longitudinal Rods 1" sq. 1' c. to c. across top
1" sq. rods 1' c. to c
Longitudinal Rods 1" sq. 1' c. to c. across whole width
1" rods 4" c. to c.
Batter 1/16:1
3'-0"
28'-0"
14'
3'-2"
13'
43'-2"
47'-5"
24'-5"
10'-7"
101'-2 1/2"
95'-10"
37'-0"
43'-9 1/4"
6'-0"
A
B
C
HOBOKEN & MANHATTAN R.R.
CAISSON No. 1
Sectional Plan C-C. Reinforced Concrete.

Fig. 3.

The method of construction adopted was (1) to build the lower portion and (2) sink it until the roof (floor of the second deck) would be at or near the surface of the ground. Then (3) to build the second deck on top of the first, after which (4) sinking should continue to the depth required by grade of tracks and (5) the invert of concrete placed. If the whole structure had been built on the surface before sinking started, the weight would have been too great to allow proper control of the sinking, and the construction of so high a structure would have been much more expensive.

Notes on Design.

The design was required to satisfy every possible condition of stress under widely varying conditions. In the first place, the lower deck had to be designed to resist the spreading, due to the inclined bottoms of the walls, and also to the pressure from the compressed air in the chamber. Rods 1½ in. diam. with ends upset to 2 in. and with turn-buckles, were bedded in the concrete and extended across the structure, tying the bottom of the caisson together; also, the 12 by 14 in. timbers which extended across the bottom were anchored into the concrete by means of several rods in each. At the level of the springing line of the arch, the horizontal timbers of the forms were anchored to take tension as well as compression. The steel cutting edge, shown in Fig. 4, was designed with very strong corners, and was anchored firmly to the concrete by cross straps and by rods which extended up the inside of the cutting edge and wall.

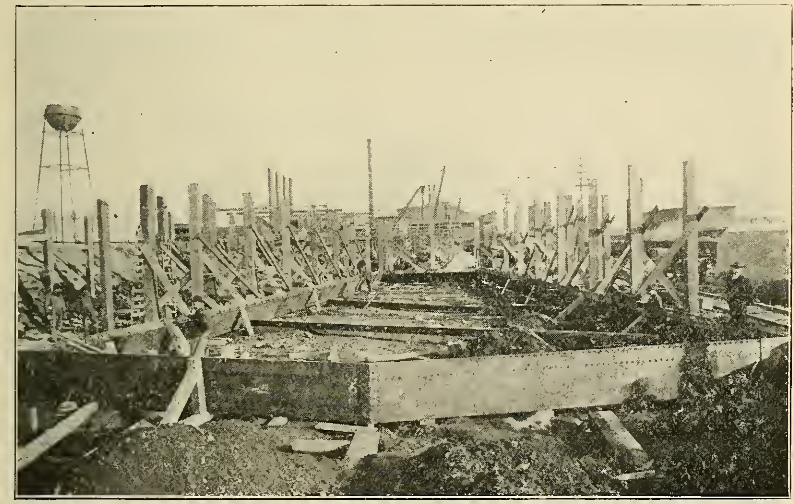


Fig. 4.

Secondly, the side walls of the lower deck had to be designed to resist the outside thrust due to hydraulic or wet earth pressure, and as the bottom was open inside the cutting edge, these forces required the 12 by 14 in. timbers to act as struts all the way down, and also required strong reinforcement in the outside portion of the wall. Square 1 in. rods of steel, were placed vertically, 4 in. c. to c. to take the tension due to the cantilever action of these forces.

Thirdly, it was necessary to design this lower portion as a longitudinal girder in order to allow for any possible uneven bearing that might occur in the sinking. For this purpose, besides the steel of the cutting edge, railroad rails were used longitudinally, with laps of about 10 ft. and ¾ in. end anchors, and also longitudinal 1 in. square rods placed near the surface of the concrete in the top.

Fourthly, the upper cover of this deck had to be designed to take compressed air pressure from either above or below, the other side being normal; to take the horizontal thrust due to the earth and hydraulic pressure on the sides of the structure and to take the weight of ballast, tracks and train in the upper deck.

Fifthly, the ends had to be designed so that they could be easily and expeditiously removed, and at the same time so as to successfully resist the air pressure from within and the earth pressure from without. To accomplish these purposes best it was decided to use three feet of concrete bounded by larger cast iron rings, large enough to allow the free passage of the shield later after the concrete had been removed.

The upper deck was not designed for quite such rigid conditions but was of course designed to carry the final static load of earth above.

As the chance for uneven bearing of the cutting edge might increase as the depth increased, the completed caisson was made still stronger as a girder by adding still more longitudinal reinforcement near the top.

The unit stresses allowed in this design were 25,000 lbs. per sq. in. of tension or compression in the steel, and 600 lbs. per sq. in. compression in the concrete.

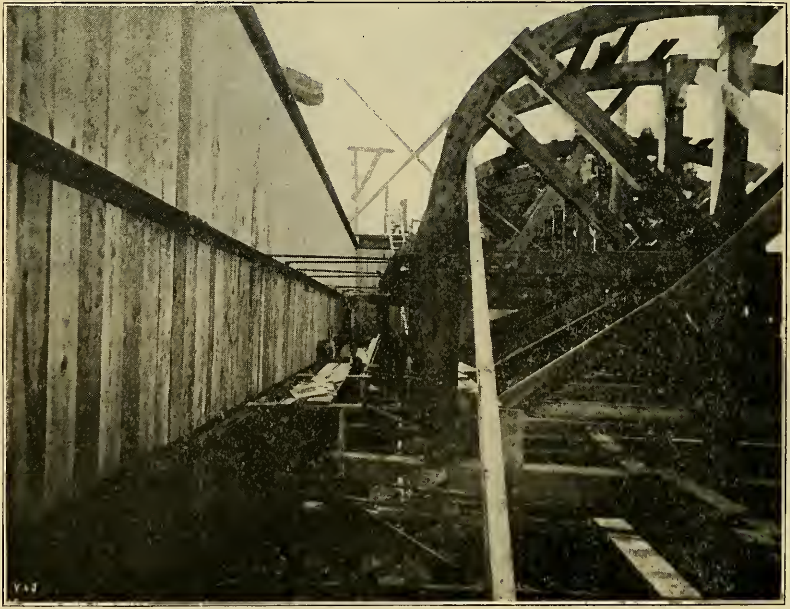


Fig. 5.

In Fig. 5 are shown some of the details of the design which amplify the drawings, Figs. 3 and 4. The forms were left in place until the final position was reached. There is also shown the longitudinal angles, which served the double purpose of holding the outside form lagging and of spacing, by holes through the horizontal leg, the vertical reinforcing rods at the outside of the concrete; these angles also served as additional longitudinal reinforcement.

Equipment—Notes on Construction.

A stock pile of stone and sand was made between the railroad tracks facing the large end of the caisson, and a stiff leg derrick shown in Fig. 6 delivered the material to a No. 4 Smith mixer set up under one of the stiff legs. The measuring hopper, divided vertically, held 20 cu. ft. of stone on one side and 10 cu. ft. of sand on the other. Five bags of cement completed the charge of the mixer to which water was added simultaneously with the other ingredients. The mixture was always in the ratio of 1:2:4, the stone being 2 in. run of crusher. Concrete was deposited partly by locomotive cranes and partly from cars on narrow-gauge tram tracks.

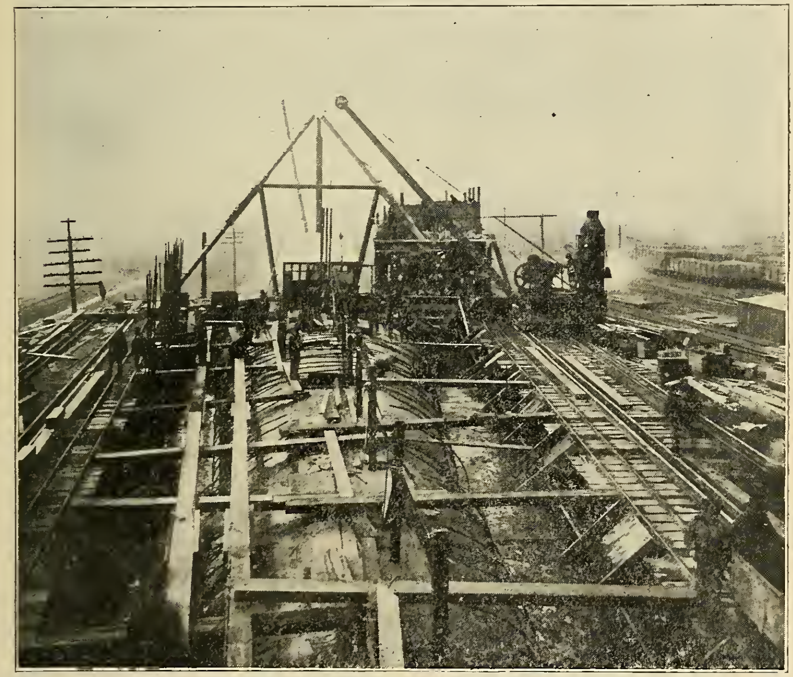


Fig. 6.

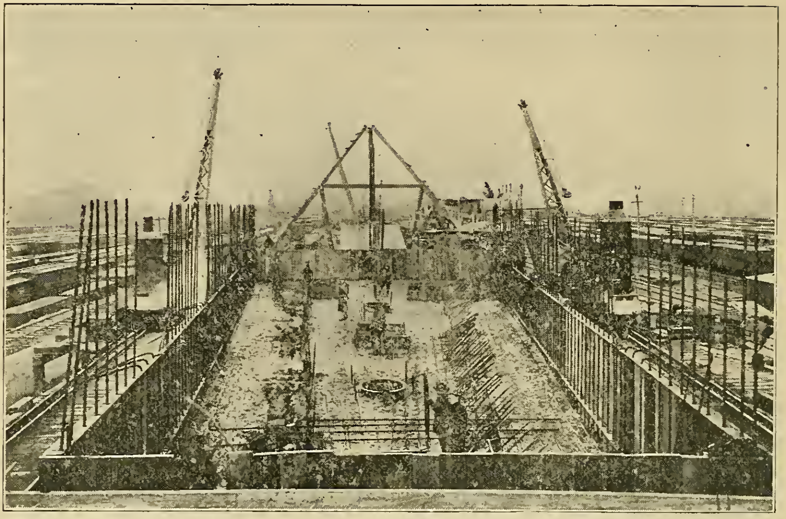


Fig. 7.

In Fig. 7 is shown the state of work on January 28, 1906, at which time the first deck lacked about twenty-four hours of completion. This shows much of the plan of the reinforcement, including the bond to the second deck.

The material locks used were the O'Rourke locks on 3 ft. vertical shafts. The same locomotive cranes were used in hoisting excavated material, as had been used in concreting.

In Fig. 8 is shown an interior view of Caisson No. 1, with its openings into the tunnels.

In construction, after the steel cutting edge had been set up as shown in Fig. 4, it was sunk about six feet lower than there shown and was leveled up at that grade. The base of the walls of the caisson was given a bearing on the mud by tamping it thoroughly under the lagging placed on the stepped forms of the bottom. It was calculated that the bearing power of the soil would be sufficient to sustain the weight of the first deck of concreting until it set. There was considerable settlement, however, during concreting, and more during the interval which elapsed before sinking commenced. This settlement was not uniform, in consequence of which the cutting edge was four feet out of level when the sinking started, and it was necessary to level up the caisson—a difficult thing to do on account of the nature of the material encountered, an old fill of non-uniform quality. It was further complicated by encountering three old sunken barges and some piling directly under the cutting edge. The caisson was finally leveled up without mishap, though to do this, pushed it laterally about twelve inches from the position planned, and the pressure from the outside against

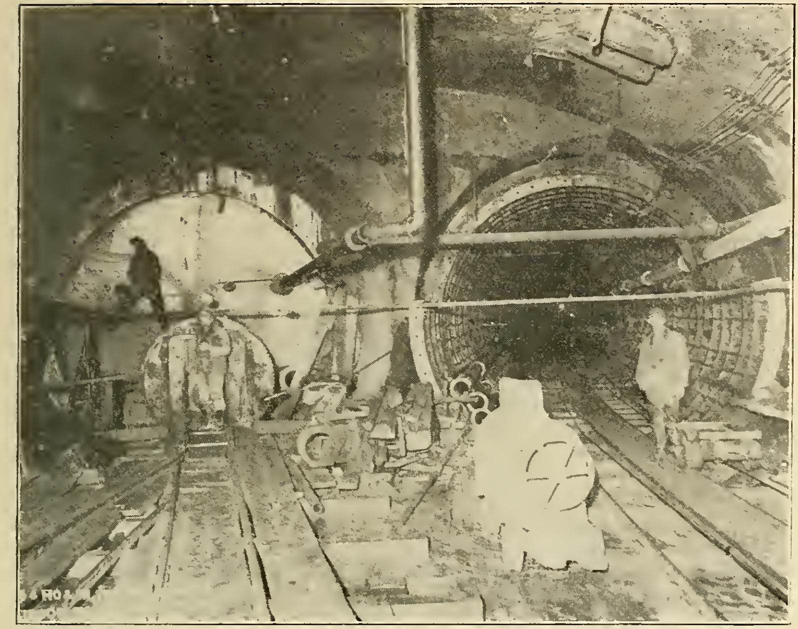


Fig. 8.

the low side was much less for a good part of the distance down than it was on the other side. This operation proved that the green concrete structure could withstand severe strains. Th final grade of the cutting edge was about 83 feet below the surface of the ground, or about 77 feet below mean tide level.

Construction work of the caisson was begun on November 30, 1905. The cutting edge was bolted together by December 14th, and forms and reinforcement were ready so that concreting was started January 18, 1906, and the first deck of concreting was finished January 29, 1906.

The sinking was delayed in starting owing to failure in the delivery of the lock shafting, and did not start until February 26th, from which date until June 6th the sinking continued, with a two weeks' interval only, at the time of construction of the second deck. The invert was placed June 7th-12th, after which the timber forms were taken apart and removed through the lock shafts under normal atmosphere. The south, or lower, tunnel (tunnel "B"), was driven into the east end of the caisson July 5, 1906.

The reinforcement used was all either second-hand railroad rails, or 1 in. square, O. H. steel bars of 0.12% carbon, which bars were delivered to the job as plain square bars. The original plan was to use them plain, but experimental tests showed a considerable increase in strength by twisting, and accordingly the Turner Construction Company, No. 11 Broadway, New York, was engaged to twist them, for which purpose they set up a twisting plant on the job.

The lower deck was made air-proof, or rather the concrete walls and top of the lower deck were aided in holding the compressed air by the use of a water-proofing process invented by Mr. H. Pashke, Chemical Engineer. A two-ply coating of asphalt saturated canvas, with three coats of a cold solution of asphaltic tar (fluid down to below 32 deg. Fahr.) were used, the application being directly on the inside lagging and hence next to the concrete surface. This material of course came off with the forms.

One feature which makes this work very interesting is the great depth of the working chamber and consequent great surface exposed to the air pressure. It was a bold scheme to make the cutting edge so far below the roof of the chamber and to depend almost entirely on the strength of the reinforced concrete sides and arch to withstand the strains encountered during sinking. This construction demonstrates, perhaps more than any structure previously built, the universal adaptability of reinforced concrete as a building material.

To sink the caisson to its depth (83 feet) required the excavation of about 11,000 cubic yards of material, of which a large amount was of solid rock requiring some blasting, but it was soft enough to be partly handled by means of picks and bull points. It was of course necessary to break it up into pieces small enough to be loaded into the caisson buckets. About 5,000 cubic yards of this material was dumped on top of the caisson after its top had gone below the ground.

The methods used in the design of caisson No. 2, and in its construction and sinking, were almost identical with those employed at caisson No. 1. The trestle had to be higher on account of getting a required 22 ft. clearance over some important yard tracks in the D. L. & W. R. R. Yard, and a 42 ft. bridge had to be provided to cross these tracks to get to a canal where the schooners in which stone and sand were received, and to which also the excavated material was delivered.

Both caissons, Nos. 1 and 2, are in the finished portion of the work (see Fig. 1), and the present traffic passes through them. Caisson No. 3 is built and sunk to its final position. Tunnels C, D, E and F (Fig. 2), are all started from caissons Nos. 1 and 2, but none of the tunnels are yet connected to caisson No. 3, which differs radically from the other two. In the first place it is built large enough for each deck to contain a double crossover instead of only a single turnout, which makes it about 50 per cent. larger in area. Details of the design of this, are shown in Fig. 9. At both caissons, Nos. 1 and 2, it was very difficult to sink the caisson the last ten feet, so No. 3 was designed with the cutting edge relatively 10 feet higher. This leaves it with the steel cutting edges directly across the middle of the circular tunnels, and these will need to be cut away when the tunnels are connected to the caisson. Placing the cutting edge higher saved a considerable amount of excavation, as the corners at the bottom were left rounded instead of squared out. The shape of the cutting edge was improved by giving it a width of about 6 inches on the bottom instead of having it come to a sharp edge.

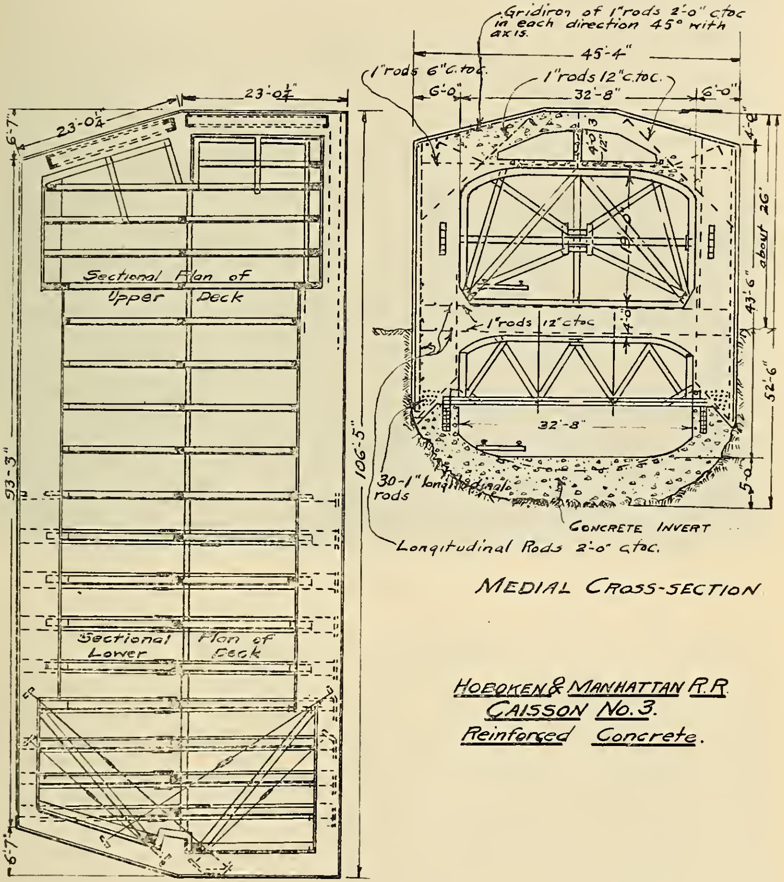


Fig. 9.

The most radical departure from conservative methods, however, was in the sinking. In the other caissons, pneumatic pressure up to 28 pounds above normal was used, but in caisson No. 3 the work was done under atmospheric pressure, which saved the slow work due to removing the excavated material through the air locks, and resulted in a material saving in the labor account, because common laborers took the place of the "sand-hogs." The water was kept down by pumping, the best results being obtained from the use of steam pulsometers, of which there were five on the job.

In Fig. 10 is shown the cutting edge erected and the sinking started.

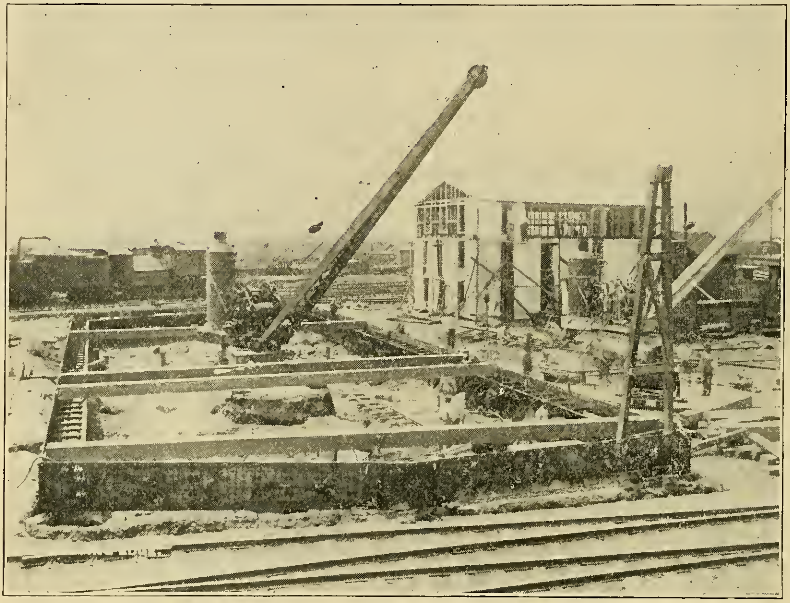


Fig. 10.

Some of the difficult material encountered in this first excavation is shown in Fig. 11, it being an old railroad fill of rock, and an old pile foundation which extended 36 to 40 feet below the ground level. At the top, these piles were arranged in regular rows, but down at about ten feet above their points there was no shape or form to the spacing arrangement. In many cases three or four piles had closed in together a few feet below the top of the ground and followed the rest of the way down together.

The material encountered in all these caissons was nearly the same: viz., about 16 feet, of fill varying from cinders to pieces of trap rock of over 1½ cu. yds.; then 10 to 20 feet, of blue clay, then in turn, quicksand, coarse sand and gravel, and finally about 25 feet of seamy sandstone rock, too hard to pick and shovel easily and requiring blasting. Caisson No. 3 went through all this material without the aid of air pressure, and the cutting edge, from the time concreting began until it reached the rock with 25 feet yet to dig, was buried in the mud from 4 to 8 feet, which helped to keep the water out and the quicksand and other material from coming in. Facilities were at hand at all times, if required to put the working chamber under air pressure on short notice, and to continue the work without interruption.

The saving to the Hudson Companies by use of the open shaft method, instead of with compressed air, was probably about $30,000.

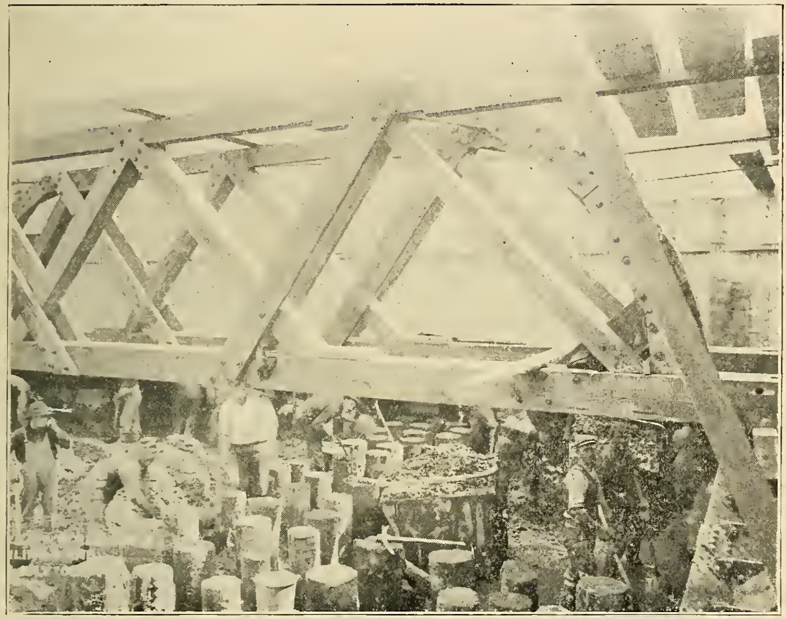


Fig. 11.

The Hoboken Terminal Station.

This terminal is constructed entirely of reinforced concrete, with the exception of the cast-iron columns and the I-beams in the roof of the concourse. Cast-iron columns were used to save space, it being thought that reinforced concrete columns of sufficient strength would be unsightly on account of their size. I-beams were used in the roof of the concourse in order to make it as shallow as possible to save vertical head-room under the street railroad tracks. About 8,000 cu. yds. of concrete and 600 tons of square twisted steel bars were used in this construction.

Practically the whole of this terminal is directly beneath the busy street car tracks terminating at Hoboken, but the entire work of excavation, timbering, and concrete construction has been carried on without appreciably disturbing the traffic above.

The roof of the terminal was designed to carry a total load of 1,500 lbs. per sq. ft., which was the estimated weight of the roof itself, of the earth back-fill, and of the live load. This unit of 1,500 lbs. was used throughout. The foundation at the west end of the terminal rested on a natural bed of soft, partially disintegrated rock; in the middle, on a bed of blue clay, but for the full easterly half of the terminal nothing was encountered in the excavation but filled-in ground; this, however, was solid and no piles were driven to increase the bearing power. The design assumed that the total weight coming upon the roof was distributed evenly over the foundation, and the bottom was therefore designed for the same unit loading as above stated. The buoyant force due to displacement below sea level was neglected except where actually sufficient to cause flotation, in which case enough weight was added to take care of that feature.

We were indebted to Professor Lewis J. Johnson, of Harvard University, for the formulae used in designing the work. For the most part, use was made only of the formula $M = Kbh^2$, in which M is the bending moment, K a factor worked out by Professor Johnson from the moduli of elasticity of steel and reinforced concrete, and b and h the breadth and height of the section of beam or slab under consideration.

The unit stresses used were 16,000 lbs. per sq. in. tension for the steel, and 500 lbs. per sq. in. compression for the concrete, the values for K being taken on the basis that the modulus of elasticity of steel equals ten times that of concrete. The percentage of reinforcement to the concrete in the cross section is usually 0.6% to 0.8%. In all cases the height—"h"—used, is the distance from the reinforcing plane to the outer edge of the compression side of the slab or beam.

The extreme westerly end was made sufficiently large to erect the tunnel shields, and was also designed to resist an air pressure of 30 lbs. per sq. in. from the interior, as well as to take the exterior strains for which the whole structure is designed.

Fig. 12 shows cross sections taken between the end of the circular bore and the Hoboken terminal. The top and bottom slabs for the clear span of 27 feet are 4 ft. 4 in. in thickness, the analysis of a 12 in. section being as follows:

$$M = \frac{wl^2}{8} = \frac{1500 \times 29^2}{8} = 157{,}700 \text{ ft. lbs.} = 1{,}892{,}400 \text{ in. lbs.}$$

Taking a value of K corresponding to 0.6% reinforcement, and $b = 12$, $M = Kbh^2$, gives a value

$h = 46$ in. net depth (4 ft. 4 in., gross depth), and

$0.006 \times 46 \times 12 = 3.31$ sq. in. of reinforcement required.

The spacing of the 1 in. sq. rods was taken at 3.5 in. and the plan shows these arranged in two planes, 7 in. apart in each.

The compression due to reactions from the side walls was neglected, as it would be in the lower portion of the slab and would only tend to reduce the tension therein.

The calculations of the other spans in the roof and floor, and the stresses in the side walls of the station were calculated in the same manner. The unit stress per square foot against the side wall was also taken at 1,500 lbs. per sq. ft., which is about what the hydraulic pressure from liquid mud at the middle height of the wall would figure. Account was also taken of the vertical load from the roof and base. The vertical walls in this portion of the station are, as shown in the plans, each one foot thick with vertical rods 3 ft. c. to c. near each side. These walls furnish ample bearing for the reaction of the roof and bottom slabs.

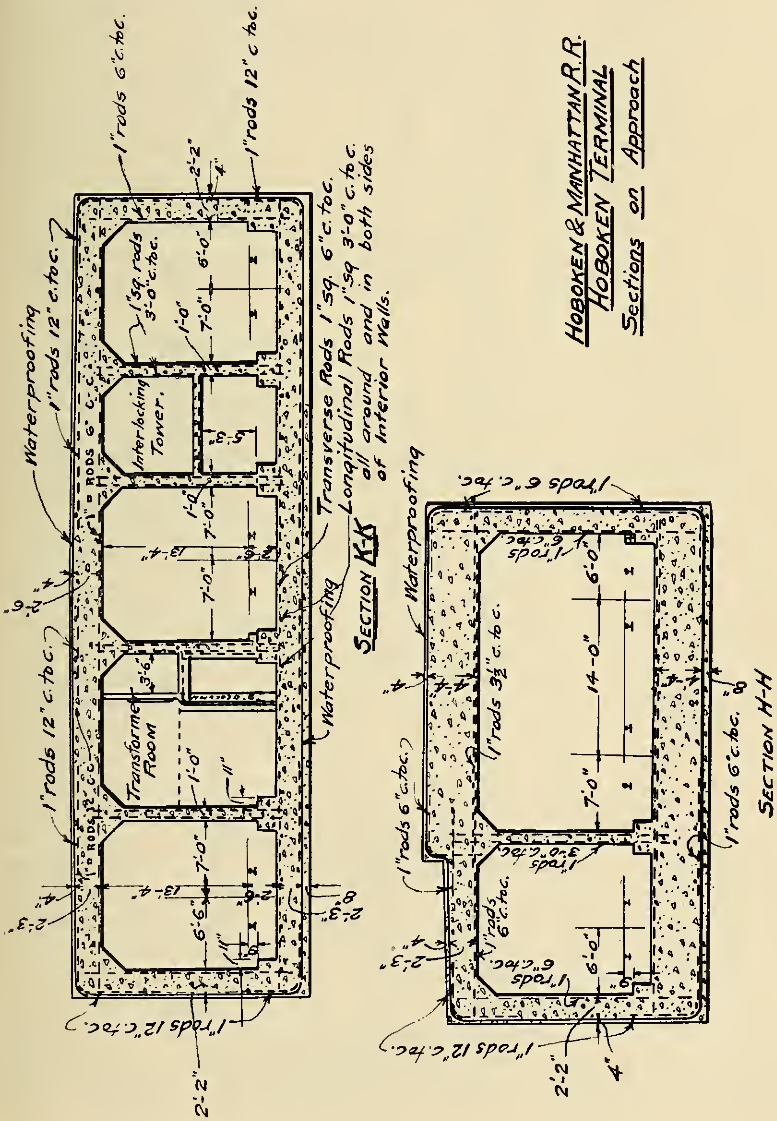
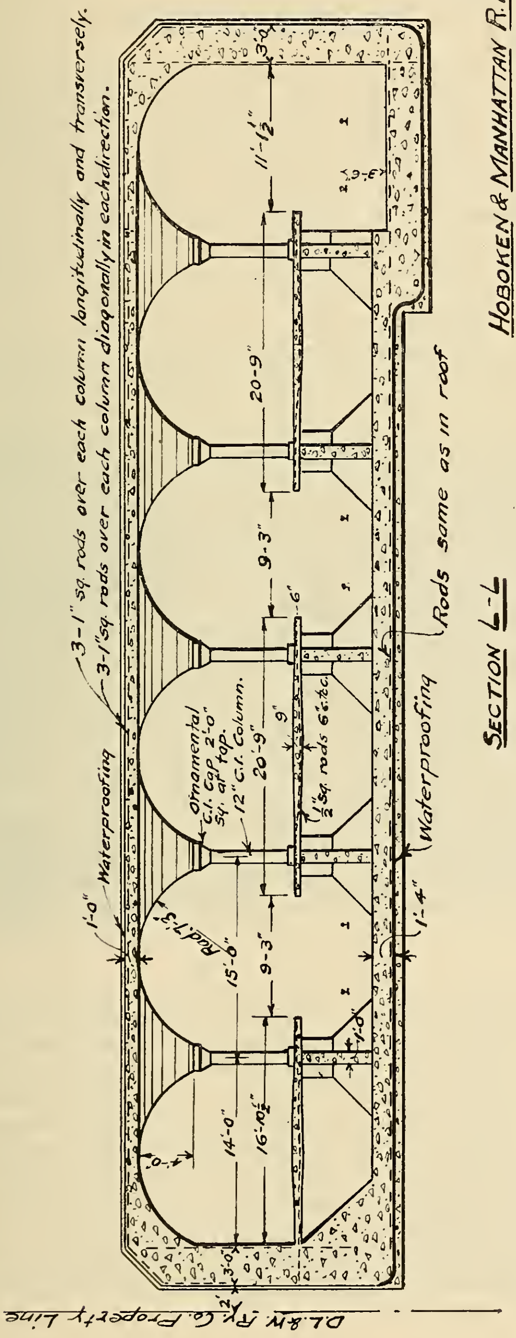


Fig. 12.

The roof, base and side slabs were all strengthened by practically shortening the span through the use of counter flexure reinforcing rods. In section KK (Fig. 12) in the roof slabs the tension rods for flexure are placed near the bottom, but by virtue of additional rods placed over the supporting walls near the top of the slab, the span is practically shortened; or, we may say, the slab is practically fixed, and we could probably have used in the analysis $M = wl^2 \div 10$ instead of $M = wl^2 \div 8$, as would be the case in a simple span. The corners are also protected in this same manner by counter flexure rods extending around the corner near the outside for this same purpose. It is believed that these rods so placed have the same effect in fixing the direction of the slab or in shortening the span, as do the rods placed over the support near the surface in continuous spans of horizontal slabs. Thus, in this whole design, all spans either vertical or horizontal were made practically "continuous girders," although in calculating strains and designing the sections no allowance was made for this. To further increase the strength of these slabs, the upper corners were beveled and the lower corner stepped, as shown in Fig. 12.

A typical cross-section of the station proper is shown in Fig. 13, which structurally consists of a system of groined arches above to take the load of the roof, the superincumbent fill, and the street and street traffic above; a system of inverted groined arches below to distribute these loads evenly over the entire surface of the foundation; and side walls proportioned to resist the same stresses as the side walls in the other portions of the terminal heretofore discussed. The groined arches in the base were made pyramidal; that is, plain surfaces were used instead of the curved surfaces in the roof, the object being to save time as well as expensive form work. The reinforcement in the groined arches in the top and bottom is of the umbrella or mushroom type. Sets of three, 1-in. square rods extend from column to column in the direction of the station, at right angles thereto, and also diagonally in each direction, these rods being near the surface of the concrete and being continuous over the supporting columns. Every square 15 ft. by 15 ft. with a column in the center is, with its superincumbent load, supported by that column, and the twelve inch thick concrete bounding the four sides of the square with the reinforcement mentioned is sufficient to carry the uniform load by cantilever or umbrella rib action to the column. In construction, however, the reinforcement was made continuous from column to column in all directions, as well as across the column, thus giving additional strength in the thin portions to better care for any possible concentrated loads.

In order to strengthen the concrete against crushing where the groins rest on the columns, nine 1-in. square, twisted steel rods, about 5 ft. long each, were stood up in the capital, eight slightly inclined in all directions from the vertical, and one extending verti-


3-1" sq. rods over each column longitudinally and transversely.
3-1" sq. rods over each column diagonally in each direction.
Waterproofing
1'-0"
Rad. 7'-3"
15'-0"
9'-3"
20'-9"
9'-3"
20'-9"
11'-1½"
3'-0"
3'-6"
ornamental C.I. Cap 2'-0" sq. at top.
12" C.I. Column.
9"
1½" sq. rods 6" c. to c.
6"
1'-0"
14'-0"
16'-10½"
4'-0"
3'-0"
2'
1'-4"
Waterproofing
Rods same as in roof
D.L.&W. Ry. Co. Property Line

HOBOKEN & MANHATTAN R.R.
HOBOKEN TERMINAL
Section across Platforms

SECTION L-L

Fig. 13.

cally in the middle of the capital and all bedded in the concrete in that position.

The platforms are reinforced concrete slabs resting on walls one foot in thickness in the line of the columns. The reinforcing iron is continuous over the support and sustains the overhang by cantilever action. These platforms are 9 in. thick at the center of the spans and tapering to 6 in. at the edge, as shown in Fig. 13.

The entire length of the north track opposite the station platform is, as indicated on Fig. 13, a track car inspection pit, the rails being carried on insulating wooden blocks resting on concrete piers, 5 ft. c. to c., thus giving ample room for workmen to move about under the cars. For this purpose the bottom slab of this portion of the station was lowered and thickened to make it similar in design to the bottom slabs in the other portions of the terminal.

In the case of the platforms in the body of the station, a space some 5 ft. high and 13 ft. wide is left below the platform slab. The operating department will probably find this space very convenient for storage purposes.

Notes on Construction.

The site chosen for the terminal was the triangular piece of ground bounded by the D. L. & W. Railroad Yards, Hudson Street, and Hudson Place, Hoboken. This ground, two years ago, was all occupied by the tracks and equipment of the street car line of the Public Service Corporation, two of the tracks coming into the Yard on the elevated incline partially shown in Fig. 14. This figure shows the work at a very interesting stage, the excavation here being nearly completed. It is held open by means of 10 in. by 10 in. timbering between the sheet piling on the sides, while the elevated railroad structure is supported above. Ground was broken for the terminal about the middle of December, 1905, but work was not pushed until the spring of 1906. As the excavation progressed, sheet piling and timbering were placed to hold it open, the sheet piling being, for the most part, not longer than twelve feet and driven by small steam hammer pile drivers, either steam or compressed air, at about 90 pounds per square inch being used. In some cases as many as three sets were used before the bottom was reached. By September 1, 1906, the excavation was complete at the extreme west end, and concreting was commenced. The mixer was a Judd Mixer, and the concrete was transferred from the mixer to its place by Koppel side dump cars on a 24-inch gage track, supported on the excavation timbering. It was possible in a good share of the work to dump the concrete exactly where it was wanted from this track without rehandling. As shown in the plans already referred to, it was necessary to surround the whole work with a waterproofing envelope, which was protected by eight inches of concrete on the bottom and four inches on the sides and top. The waterproofing material chosen was a burlap saturated with an asphaltic tar solution and an asphaltic tar with a melting point of about 120 deg. Fahr. In the terminal proper (the length of the platform) five ply fabric with six coats of pitch were used. In the portion west of the west end of the platforms three ply cloth with four coats of pitch was used.

The main advantage gained in using the burlap fabric instead of a felt for the waterproofing was the facility in making connection between old and new waterproofing where work could not be made continuous. The envelope of waterproofing is now completed, but because of the large amount of timbering and the necessity of suporting the elevated railroad structure as well as the surface railway east of the foot of the incline, the concrete work, as well as the waterproofing, was necessarily done in small sections and often with many openings for timbers. This made the waterproofing in some places a succession of patches, but in every case where patching was required, or where new work was joined to the older, all the laps were opened up for at least six inches, and the junction in the three or five ply waterproofing was dove-tailed as many times as there were laps. Thus, in the five-ply work for six inches at the junction there would be eleven coats of tar and ten alternating thicknesses of the cloth, making the laps more waterproof than the body of the waterproofing, which could not possibly be the case if felt were used, as it is practically impossible to open up and dove-tail the laps of felt

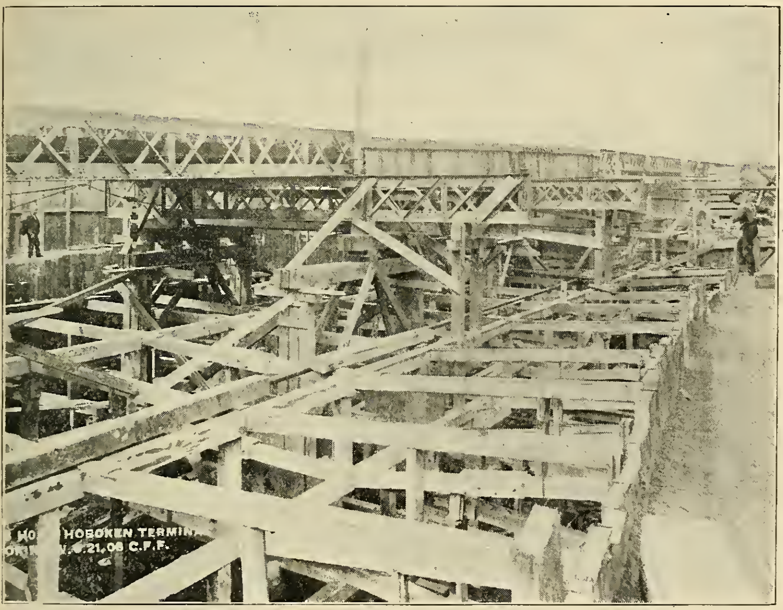


Fig. 14.

waterproofing in this manner. Fig. 15 shows the use of clay tile partition blocks for the side waterproofing protection instead of the four-inch concrete called for on the plan. Several thousands of these partition blocks were used in various parts of the work where serious delays might have been caused had concrete been insisted upon. In this view the eight inch bottom protection of the waterproofing has been placed and the waterproofing thereon. After this about two inches of protecting concrete was placed to prevent the waterproofing fabric from being torn by the workmen in placing rods for the bottom slab, and in other work before the slab was placed. The waterproofing had been turned up the side wall a foot or so when placed and, in this view, it is shown pulled away and the laps separated so as to start the waterproofing on the side wall and allow the dove-tailing as described above.

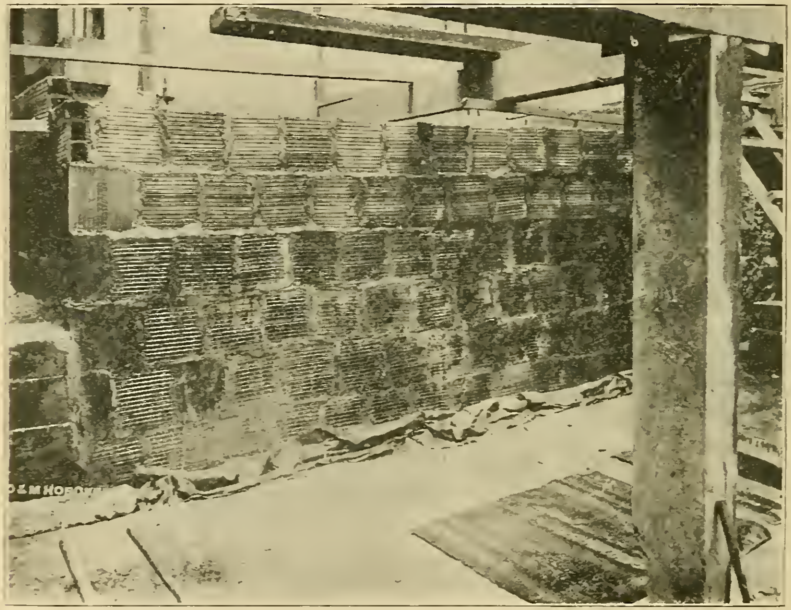


Fig. 15.

The work is almost entirely below tide so that considerable pumping had to be done in order to keep the excavation dry during the progress of the work. Small ditches dug slightly lower than the general bottom of the excavation led to the sumps and, in order to allow the bottom waterproofing protecting concrete to be placed on a dry bottom, these ditches were bridged over with boards or were tiled. Some of the main ditches were kept open until a later stage to allow cleaning, if necessary, but, after the concreting was practically all done, these ditches were also bridged over and all the sumps but one were abandoned and filled. The water from this sump was pumped out all through the work by one or more of several kinds and sizes of pumps, but in the end, there remained one large centrifugal pump with a 14 in. suction and a 12 in. discharge and two piston pumps with 5 in. suctions and discharges. Either the large centrifugal pump working alone or the two 5 in. pumps working together could keep the sump from overflowing. To seal this sump the smaller pumps were used, while the suction to the centrifugal pump was changed to 12 in. and with a gate valve. There was first laid down on supporting boards, eight inches of protecting concrete, and then the waterproofing patched in, as elsewhere, flashing this up and around the suction pipes as well as an additional 3 in. pipe with open end, which pipe was extended up through the station to above tide level. After the concrete was fully set, while working the large pump, the small pumps were removed and their suction pipes filled with cement grout, thus closing those outlets. After this grouting had set, the gate valve on the 12 in. suction was closed, and the large pump removed. Some days later the cavity of the sump and, probably, back some distance in the drains, was filled with cement grout through the 3 in. pipe above mentioned. To do this more effectually a tunnel grouting machine, worked by compressed air at 90 lbs. per sq. in., was used, forcing the grout into all cavities. When the grouting was nearly completed, the 12 in. gate valve was partially opened to permit the water to escape and that the grout should fill this pipe up to the gate valve. After this grout had thoroughly set, the valve and the 3 in. pipe were removed, and the openings cemented over flush with the adjoining floor, thus leaving no outward trace of the sump.

The transferring of the vertical loads on the temporary timber posts supporting the street railway structures and the horizontal timbering, was very interesting. At the completion of the excavation the vertical posts were left standing on short horizontal cross timbers resting on the mud bottom of the excavation. In general the tops of these short cross-timbers would be at the general level of the finished excavation and, preparatory to placing the bottom eight inches of waterproofing protection concrete, the posts would be boxed in with 1-inch lumber, 10 inches wide, the box being made slightly larger on the inside than the dimensions of the post. After all the posts in the area to be concreted were thus fixed the eight inches of concrete was placed and finished off to accurate grade. After this concrete had set, the waterproofing was placed and protected with an inch or two of small stone concrete, short 3 by 6 in. timber blocks being placed around the post boxes on the waterproofing so as not to cover that portion of the waterproofing required for waterproofing lap. The vertical posts were then transferred; that is, other posts were set up near these posts on the finished waterproofing, so placed as to relieve the load on the original posts. These latter were then sawed out and removed, the boxes taken out, the holes filled in up to the waterproofing level with concrete, the waterproofing patch placed, the laps were dove-tailed as heretofore described, plenty of tar always being used in such cases, and then this portion of waterproofing was covered over with the one or two inches of concrete mentioned above. The next stage of work was to bulkhead off with temporary vertical bulkheads, sufficient of the bottom slab of the reinforced concrete for one day's work. The vertical posts were then boxed off with boxes just large enough for the purpose, and of a height slightly more than the thickness of the bottom slab. The reinforcing rods called for in the bottom portion of the slab were then placed, the ends being passed through the bulkheads to bond with the next day's work. Rods in all cases were made continuous by lapping them at least forty diameters at their ends and tying these ends together with two or three wraps of No. 18 pliable wire to hold them in position. The concrete was then placed into the area, being dumped through a shute from the Koppel side-dump cars on the track above. The shutes were moved about so as to require a minimum of rehandling in placing the concrete. If, in the area, the plan called for rods near the upper surface of the slab, these rods would be placed in the wet concrete when it was filled up to the proper level without stopping the concrete, these rods also being passed through the bulkhead if necessary for bond with adjoining work. After this concrete was set the posts were again transferred as before described, the boxes removed, and the holes filled with concrete completing the slab. The posts were transferred in such manner as to allow, without interference, the construction of vertical walls or the pyramids for the column pedestals.

In all of the main station platform portions of the work the next stage consisted in placing the pedestals, columns, and capitals; also the side walls up to the spring line of the arched roof. The groined arch form work was made with great pains so as to leave a finished concrete surface after stripping. Use was made of 2 in. by 4 in. lagging with radial bevel edges; this being made continuous in one direction of arch, the lagging in the other direction being trimmed to fit. A line was marked on the first lagging from center to center of groin across the center of the column, diagonally in each direction, this line being obtained by plumbing down from a chalk line held on the center of the groins. Care was used to run the secondary lagging to this line.

In order to carry the load of the street and the street car traffic above, it was necessary to leave the vertical posts which extend up through this work. They had to be boxed off from the lagging up to the finished top with boxes made large enough for a man to work in after the posts should be removed. After concreting, the loads above were transferred and the posts removed, after which carpenters completed the lagging where broken, and the holes were filled. In transferring these posts much care had to be taken to have the heavy concentrated loads come very close to a point directly over a cast iron column.

The top of the concrete roof came so close to the under side of the horizontal and longitudinal timbers supporting the street and the street car traffic that work was carried on with great difficulty; carpenters worked on the forms with hardly room enough to strike a blow with a hammer; those putting away concrete worked on elbows and knees; and for waterproofing it was necessary to pick out small men and boys in order to do the work at all.

After the waterproofing was finished, except at the posts, it was covered with the protecting concrete called for on the plans, the load was transferred to it, and the waterproofing patched where the posts had been. After this the timbers underneath the ties of the street car tracks and the planking were removed. The ground was filled over the finished station to the original level, and the ballast under and between the ties and the street paving was restored.

In the meantime, all the excavation, timbering and concrete forms inside the station were removed, the one-foot vertical walls to support the station platforms were built and also the reinforced concrete platforms. The granolithic work in the concourse and on the station platforms was made of cement mortar in the proportion of one part of cement and one-half part screened Cow Bay sand, no lamp black or other coloring being used. In building the arched concourse floor and the platform slabs, concrete in its ordinary proportions was placed up to within one inch of the finished grade, the granolithic mortar being added almost immediately in order to be able to count on the whole thickness for strength. The granolithic workers leveled it off and worked it to grade before leaving it for the night.

The concrete mixture, in general, consisted of 1 part of Giant Portland cement (accepted after rigid inspection by the Company's inspectors, and always at least five weeks' old), to 2½ parts of Cow Bay sand and 4½ parts crushed trap rock and gravel. The crushed rock came from the stone crusher of O'Neill & Hopkins, Jersey City Heights, and the run of the crusher was used from two inches to screenings. The gravel was from Long Island, ¾ in. size. The proportions of crushed rock and gravel to make up the 4½ parts of aggregate varied according to the nature of the work. In some cases no gravel at all was used, but usually about half gravel and half crushed rock was employed; and occasionally some small pieces of work were done with gravel only. Wet concrete, according to most modern specifications was used, the degree of wetness being such that when placed in the forms, a man from his own weight would sink into the freshly deposited concrete nearly to his knees. In some of the bulky portions of the work, stones and boulders found in the excavations were imbedded in the concrete. Before placing the concrete in the forms, the face of the wooden forms was filled with paraffine oil to prevent absorption of water from the concrete as well as to aid in making a smooth face on the concrete.

The reinforcing steel used was 1 in. and ½ in. square twisted steel bars, furnished by the Turner Construction Company. They conformed to the specifications of the Hudson Companies for square O. H. steel bars of 0.12% carbon, to be twisted cold, with one complete turn in a length of eight times the side of the square. Tests made at Columbia University showed that this quality of steel gained about 25 per cent. in ultimate strength and elastic limit by twisting it in this manner. In making hook ends on the rods or any right angle or other bend, they were always bent cold. The rods came to the work in twenty, thirty and forty foot lengths. When other lengths were needed they were sheared to length by the use of Watson-Stillman hydraulic shears—a very ingenious tool, easily allowing two men to make thirty or forty cuts per hour of 1 in. rods.

Tunnel Lining.

A typical cross-section of finished tunnel ready for ballast and track is shown in Fig. 16. The slabs on the central line of the bottom are of reinforced concrete, 14 in. by 30 in. by 2½ in., the reinforcement being a large mesh expanded metal sheet near the bottom surface of the slab. These slabs cover a drain 9 in. wide by 5 in. deep. The side walls contain vitrified clay tile conduits, twenty holes on one side and fourteen on the other. Additional longitudinal stiffness was given to the tunnel by placing eight 1-in. square twisted steel rods longitudinally in the concrete lining, two on each side of the invert drain and about 6 and 10 inches away from its

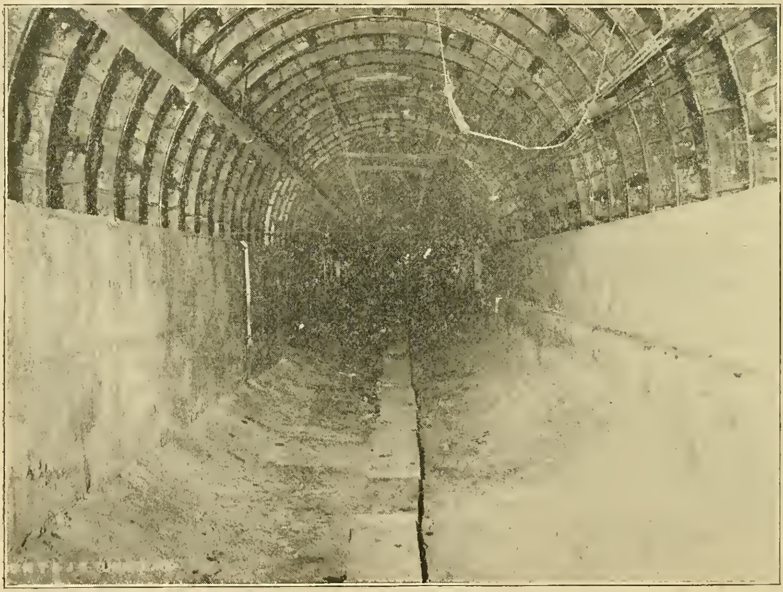


Fig. 16.

edge respectively, and two on each side in the bottom of the side wall. For duct wraps, a single thickness of asphalt-saturated cloth, coated with soft tar, was used. These proved to be much more reliable than muslin wraps saturated in grout, as we found practically no joints where mortar from the wet concrete had penetrated into the ducts.

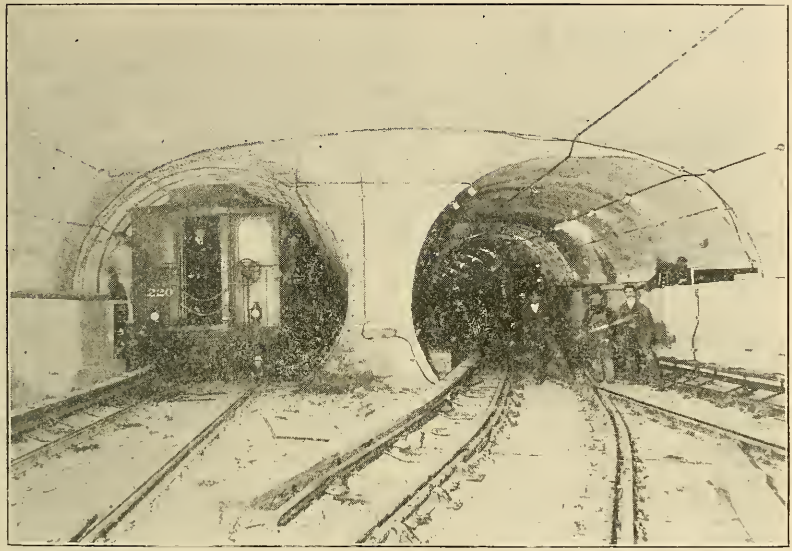


Fig. 17.

In Fig. 17 is shown the tunnel enlargement for crossover on the New York side, which was made from the circular cast-iron tunnels. In the first place two parallel cast-iron tunnels under Christopher Street were driven in the usual manner, and then afterwards, piece by piece, the cast-iron lining was taken out and the reinforced concrete arch substituted. Being so much wider than high, the outside segments of the iron also had to be removed and space made outside to carry heavy concrete walls for the abutments of the over arch and the invert arch. The reinforcement was made continuous all around by lapping the rods through the temporary bulkheads where work stopped for the day. This work was done without losing any ground.

The design and construction of all the work here described was under the direct supervision of Mr. Charles M. Jacobs, Chief Engineer, Mr. J. V. Davies, Deputy Chief Engineer, Mr. G. D. Snyder, Principal Assistant Engineer, and Mr. R. S. Courtney and Mr. V. Messiter, Work Managers.

My own position was Assistant Engineer in charge of reinforced concrete design, and while holding that position I designed Caisson No. 1 and part of the Hoboken Terminal. Later I was Superintendent of Concrete Construction in direct charge of most of the construction herein described.

DISCUSSION.

Mr. John M. Ewen, M.W.S.E: I would ask Mr. Torrance how the tunnel for the Erie tracks, running along to Jersey City, was constructed? Were the caissons made and sunk the same as in the other cases shown?

Mr. Torrance: The tunnels were driven in the railroad yards in the same manner as under the river, the theory being that the circular tunnel will maintain its shape on account of the near equality of pressure from all sides. Of course, where we had to make the tunnel wider than high we had to use some other design, in order to take care of the extra weight above and below as compared to that at the sides. The circular driven tunnels are used everywhere for single track use.

President Lowcth: What were the dimensions of the largest caisson?

Mr. Torrance: The length was 106 ft. and the width 46 ft. That caisson was sunk without using compressed air.

Mr. W. B. Jackson, M.W.S.E.: I understood Mr. Torrance to say that they were able to reduce the expense a good deal by not using compressed air. Can he give us an idea of the proportionate amount of this saving?

Mr. Torrance: The cost of concrete construction was practically the same per unit. Of course the largest caisson cost more than either of the other caissons, but on the cost of the sinking there was saved, roughly, one-third, or somewhere between one-third and one-half of the cost of our labor.

President Lowcth: Was there not a great saving in time, made by that method?

Mr. Torrance: Not so very much, largely because of the obstacles encountered, in the way of unexpected rock which had to be taken care of. Also, in the first place, a type of pump was selected which proved to be unsatisfactory, and twice during the work the caissons filled with water which had to be pumped out before work could be resumed.

Mr. J. M. Ewen: What air pressure was used?

Mr. Torrance: Up to 28 pounds per square inch, in Caissons Nos. 1 and 2.

Mr. J. M. Ewen: Did the men experience any difficulty in working at that high pressure?

Mr. Torrance: There was very little trouble in the caissons with the men working under compressed air; the large space seemed to have some effect in aiding them to stand it. In the tunnels the men were affected more than in the caisson work. In the tunnel there was a good deal of leakage and the air to make up the loss, coming fresh from the compressor, would be hot, sometimes as high as 90 deg. Fahr.

Mr. J. M. Ewen: How long at one time did the men work under that pressure?

Mr. Torrance: They worked eight hours per day, but were really not in the caisson longer than four hours at a time. Shifts started at eight A. M. and four P. M. and at midnight.

Mr. T. L. D. Hadwen, M.W.S.E.: You made use of a low unit compression stress for the concrete. Do I understand you to say it was only 500 pounds?

Mr. Torrance: Yes, that is right for the Hoboken tunnel.

Mr. Hadwen: Was that unit stress used also on the caisson work?

Mr. Torrance: We used a somewhat higher stress on the caisson work because the heaviest stresses were the temporary ones. We used 25,000 pounds in the steel.

President Loweth: For permanent work the assumed unit strains in the steel reinforcement were 16,000 lbs. per sq. in., and where the stresses were merely temporary during construction, unit strains of 25,000 lbs. were allowed! Is that correct?

Mr. Torrance: Yes, sir, as in caisson No. 1 it was designed as an alternate to the steel design in which those units had been employed.

President Loweth: Even with those high strains you had no cracks, I believe.

Mr. Torrance: We did not even have any hair cracks, although when we started the sinking, the concrete was green. In Caisson No. 3, the first concrete placed weighed about 3,000 tons, and while placing it, the caisson sank over 7 ft., plowing its way down and without cracking.

Mr. Ernest McCullough, M.W.S.E.: In reference to the low unit stress mentioned by Mr. Hadwen, for the concrete, this stress depends upon the value chosen for the ratio between the moduli of elasticity of the steel and the concrete, which is termed "n." Mr. Torrance stated that this value of "n" was taken as 10 in his formula, thereby making it possible to get a value of 500 pounds fibre stress in the concrete, and 16,000 pounds per square inch in the steel. If he had used the value of "n" equals 12, as required by the building ordinances of the city of Chicago, he would have been unable to use a higher stress than 10,000 pounds in the steel, if he had used 500 pounds in the concrete. Using, then, this raio as required by the Chicago building ordinance, the actual stress in this concrete is nearer 580 pounds than it is 500 ponuds.

Mr. Torrance: In the design of the Hoboken terminal the table for value of "K" as determined by Prof. Johnson, for "n" = 10, was used. For myself I am too unfamiliar with the derivation of the formulae to properly discuss whether this is strictly correct, but of course that "K," was used, which gave the greater amount of steel, whether it was "Kc" or Ks.

Mr. McCullough: Was any investigation made as to the possible disintegrating effect of the concrete, where the rods were in the side, on account of the skin friction?

Mr. Torrance: We did not consider that at all. There was undoubtedly some such strain, but our boards were planed. In caissons Nos. 1 and 2 especially, there was hardly any skin friction. It went down with compressed air, buoying it up, and the bubbling of air and water, on all sides, prevented skin friction being very great.

Mr. McCullough: It seems to me there would be some disintegrating effect.

Mr. Torrance: In designing caisson No. 3, the designer in the main office of the Company used smaller angles and did not provide threaded holes for the rods. We spaced the rods out by means or boards, fastened to the lagging, which boards were removed as the concrete arose. The designer was afraid that water would get to the rods from the outside along the angles, if they were used as in Caissons No. 1 and No. 2.

Mr. McCullough: I think that this method of spacing with the boards, without fastening the rods to them, is better, for fastening the rods to channels attached to the caisson sheeting would certainly affect the material if the sheeting moved, and would put some initial stress on the steel.

Mr. M. F. Ewen, M.W.S.E: In regard to that wet concrete, where you speak of having gone in up to your knees; how long did it take, for it to set?

Mr. Torrance: The first concrete in Caisson No. 1 was put in, in January at a temperature of about 35 deg. Fahr. That concrete was very slow in setting, on account of the cold weather. The cement was some we had had on hand for sometime, which added to the slowness in setting. In one place I saw a man go in up nearly to his waist after the concrete had been deposited nearly 24 hours, In summer, however, when the other two caissons were constructed, some of it set so rapidly that one could walk on it inside of five or six hours.

Mr. M. F. Ewen: What was the reason for changing the cutting edges?

Mr. Torrance: The cutting edges of Caissons No. 1 and No. 2, were badly wrecked on the way down; the rivets would break and the two plates would separate from each other, making a wreck of the cutting-edge by the time it got down to the bottom. We left six inches width at the bottom of Caisson No. 3 so we could have a place to block up under.

President Loweth: How efficient was the waterproofing in making the caisson water tight? Was the tightness due to the good quality of concrete or to the waterproofing?

Mr. Torrance: We did not do anything to the waterproofing except to use 1:2:4 concrete; we made the work continuous. There was no waterproofing, but the caissons were very tight. There were one or two leaks in caisson No. 2, and the Superintendent in charge of the sinking, drilled a hole out through that place and pumped grout through until he stopped the leaks. That method was followed a good deal, especially in the enlargements under the streets of New York, where they enlarged from the inside, by patch-work. In Hoboken we used the waterproofing envelope.

President Loweth: Was the waterproofing successful?

Mr. Torrance: I might say almost perfectly successful. About all the water that comes into the whole Hoboken terminal, could be put through a ¾ inch pipe. There were a few leaks where our work joins on to the D. L. & W. property. At that junction where felt waterproofing joined on to our asphalted burlap method, some considerable leakage occurred. We gave up trying to stop it there, and embedded pipes under the surface to collect it, carrying it down through the floor and let it run into the ballast of the track. But for the most part, the waterproofing was successful.

President Loweth: The speaker is of the opinion that the best way to make concrete waterproof is to make it of excellent quality.

Mr. Torrance: When we put in the invert of Caisson No. 1, there was some talk about waterproofing that. We made some tests on some waterproof cement, and concluded that ordinary Portland cement was about as good as waterproof cement. The manipulation is of more importance than the so-called waterproofing qualities of the cement. It was finally decided to use ordinary Portland cement in the bottom—with the 1:2:4 mixture. This proved entirely successful.

Mr. C. R. Dart, M.W.S.E.: I have not been able to make concrete absolutely waterproof on account of the joints. I have not used much concrete of the 1:2:4 mixture, most of what I have used being 1:2½:5 and 1:3:6. In the Chicago river we have made our pits watertight by lining with grout, making a continuous lining, and have had fairly satisfactory results. In one or two cases a little too much mortar was used, which made the lining porous, but we have had very little leakage. In one case we tried a steel lining, which was not successful. Our best results were at Dearborn Street bridge, which has practically no leakage.

Mr. Hadwen: Referring to the summer work, where they had that large area of concrete, could they get it in place and the next layer of concrete started without having a joint? Were there not some horizontal joints?

Mr. Torrance: If there were any horizontal joints, they did not give us any trouble. We always managed to cover any place which was about to set hard, before it was really hard, and make a joint as small as possible. We took pains to have men walk in it and make it rough on the surface when taking initial set, so there would be more or less of a bond with the new concrete when it should be put on. In the summer time, on account of anticipating that there would be trouble like that mentioned, it was put in faster. We put in the second deck of caisson No. 2 in nine shifts—four-and-a-half days, working two shifts, doing that 1,500 yards of concrete in those nine shifts, so as to avoid the trouble spoken of.

THE HEAT LOSSES FROM STEAM TURBINES

AN EXPLANATION

Editor Journal Western Society of Engineers.

In the JOURNAL for August, 1908, Vol. XIII, page 549, Prof. J. C. Thorpe, in a paper on steam turbines, listed the energy losses occurring with turbines as follows:

1. Friction between the steam and the metallic surfaces, both stationary and moving	10%	12%
2. Friction due to eddy currents	5%	7%
3. Resistance to the rotation of moving parts in the atmosphere of steam, called "windage"	6%	8%
4. Mechanical friction in journal bearings, glands, stuffing boxes, etc.	5%	10%
5. Leakage through clearance spaces, glands, etc.	3%	7%
6. Radiation loss	4%	8%
7. Residual velocity in exhaust		

In discussion on page 571, I stated—

> I think it unfortunate that as a general thing there has been so little discussion of the factors which influence efficiency with turbines. After all, when the matter is summed up, it would appear there are only three possible sources of loss, to-wit:
>
> a. Heat in the exhaust,
> b. Radiation from the exterior of the machine,
> c. Velocity in the exhaust,
>
> and strictly speaking, I do not think that Items 1, 2, 3, 4 and 5 given as losses on page 549 of the paper, should be so considered for the following reasons:
>
> Friction between steam and the metallic surfaces must result in the generation of heat. This heat is either returned to the steam flowing through the machine or else radiated away from the exterior of the casing, but inasmuch, however, as it cannot raise the temperature of the turbine casing from that due to normal condition, it could not contribute to the radiation loss, therefore the heat would find its way into the steam to be transferred into work, or else would escape with the exhaust. The same reasoning applies to friction due to eddy currents, likewise the resistance of the steam to rotation known as windage.

Later, Prof. G. A. Goodenough in a written communication appearing on page 574, said:

> In the question brought up by Mr. A. Bement regarding the losses in the steam turbine, we must take issue with Mr. Bement's statement that Items 1, 2, 3, 4 and 5 of page 549, should not be considered as losses. Take the case of Item 3, Resistance to the Rotation of Moving Parts in Atmosphere of Steam, or Windage. Here work is converted into heat, and as Mr. Bement states, the heat is returned to the steam in subsequent stages. To be sure, there is no loss of energy; that is, our law of conservation of energy is not violated. There is, however, a loss of availability; that is, the heat that has been produced by the work can in no way in the subsequent stages be made to give back the work that was expended in generating it. In fact, it can be made to give back only a very small fraction of that work.
>
> For example, suppose that in a given stage 10,000 foot-pounds of work are expended in windage. This means that the equivalent of 10,000 foot-

MOTION PICTURES AT MEETINGS

At several of the January meetings motion pictures of engineering and industrial activities were tried out as a means of developing interest and at the same time adding an instructive diversion from the technical nature of the subjects usually discussed. Although these pictures were projected by a rented machine, the operation of which was not entirely satisfactory, the idea immediately popularized itself, and through action of the Board of Direction a modern high-powered machine was purchased and installed in the Society's meeting room. Now motion pictures of various subjects are shown at almost every meeting.

Usually it is possible to obtain pictures illustrating some phase of the subject under discussion and in this way their use becomes very valuable in aiding the listener to visualize the ideas that are brought to him. On occasions such as "Ladies' Night" and "Students' Night" the pictures have been a source of entertainment as well as one of instruction.

Motion pictures are now recognized as one of the most effective means of instruction and their use at Society meetings has been greatly appreciated.

OPERATING RESULTS OF THE ELECTRIFICATION OF STEAM RAILROADS

Presented "Electrification Night," March 16, 1915.

By George Gibbs, Edwin B. Katte, W. S. Murray and C. A. Goodnow.

For considerable time Chicago engineers have given more or less individual study to the problems incident to the electrification of steam railroads, in anticipation of the report of the Chicago Association of Commerce Committee on the Investigation of Smoke Abatement and Electrification of Terminals. They have been handicapped, however, by a lack of information regarding results under working conditions, their data, for the most part, having been derived from the estimates of engineers who have made a more detailed study of the problems.

Early in the year the railroad engineers in the society conceived the idea of an "electrification night," the purpose being to bring before the profession the results of actual operation as obtained by the various systems which have electrified portions of their lines. Fortunately the program of meetings permitted this meeting being held during the convention of the American Railway Engineers Association in Chicago. Through the efforts of Mr. E. T. Howson, engineers from five representative railroads had consented to prepare papers giving data obtained through experience and careful recording of observations. In addition to this program there followed a discussion in which the foremost electrification engineers in the country took part.

As a result the meeting afforded an opportunity for an exchange of ideas between representative railroad engineers and a consequent understanding of what might be expected of electrification under various conditions. As brought before this meeting, the important facts regarding the electrification of steam railroads are:

(1) That the greatest determining factor is the relative density of traffic.

(2) That electrification finds its most favorable application in terminal problems and under condition of excessive grades.

(3) That any economy incident to electrification must come through operation, as the first cost is far in excess of that of steam installation.

Editor.

THE NORFOLK & WESTERN AND PENNSYLVANIA ELECTRIFICATIONS.

By George Gibbs.*

The Norfolk & Western electrification of a trunk line railway for heavy freight service is nearly completed and partial service has already been successfully inaugurated.

This line has its eastern terminus on the Atlantic seaboard at Norfolk, Va., and its western termini at Columbus and Cincinnati, Ohio. In addition to a large passenger and freight traffic, it conducts an especially important and rapidly growing traffic in coal hauled from the Pocahontas field, near the summit of the Allegheny mountains, 365 miles eastward to tidewater and also a heavy westbound coal traffic from the same field. Practically all of this eastbound tonnage must be hauled up the western slope of the mountains to the summit at Bluefield, which is 2,400 ft. above the sea, and thence generally over grades favoring the loaded movement, crossing, however, two other summits, constituting pusher grades over parallel ranges of the Blue Ridge.

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The electrified section is the "Elkhorn Grade" on the Pocahontas Division, beginning at Vivian, about 30 miles west of Bluefield, and comprehending the entire main-line gathering divison on whch the bulk of the coal tonnage orginates. It is important to note that this portion of the railway is operated as a separate division in so far as the tonnage coal business is concerned and that this traffic is handled by a special class of power which is confined in its movement to this local division. Along this line are numerous colliery sidings and short branches penetrating the developed coal field, and the normal service consists in collecting loaded cars or trains from the sidings and branches for eastbound trips and delivering empties on the return. Thus the electrified section is a local switching and short haul division between the points of origin of traffic and the classification yard at Bluefield on the east, where the trains are made up for the haul to tidewater. Because of the possibility of thus segregating the very heavy traffic both as to operation and power, there is produced a condition very favorable for electric traction. Other favorable conditions arise from the fact that the tonnage movement is very heavy and the trains may be despatched at fairly uniform intervals throughout the day, thus improving the load factor and limiting the number of locomotives required; also, that the present speeds with steam are undesirably low. The primary purpose, however, of the electrification was to provide for an increase in the capacity of the railway by an increase in operating speed; and to furnish a more economical and efficient method of handling the service over the grades.

The line is double track throughout, with frequent long passing sidings, making it in part a three track line, but the Elkhorn Tunnel is single track. Sixty per cent of the entire division is on curves, the maximum curvature being 12 degrees on the main line and 16 degrees on sidings. From the profile, it will be noted that at Vivian, the beginning, there is a stretch of about 5½ miles of 1 per cent grade to North Fork, then 5½ miles of 1.5 per cent grade to Ennis, and then about 4 miles of 2 per cent grade to the Elkhorn Tunnel, which is 3,000 ft. long, and on a 1.5 per cent grade. Leaving the east portal of the tunnel the line pitches down on a 2.5 per cent grade for about one mile, and then rises again for 9½ miles on a 0.4 per cent grade, finally reaching Bluefield over three miles of 1.25 per cent grade. The main gathering points of the coal occur along the line from Vivian to Flat Top Yard and eastbound trains must, therefore, be hauled over very heavy grades.

The eastbound coal traffic has increased rapidly, doubling in volume during the past four years; in the year 1913 it averaged 40,000 tons per day, but has frequently amounted to over 60,000 tons per day. At present the number of these tonnage trains is about 12 per day, but with the electrical equipment, provision has been made for handling 20 trains or 65,000 tons per day. In addition, provisions have been made to handle through freight trains by electric pushers and to haul passenger trains and their attached steam locomotive with an electric engine. In this latter case the necessity of an electric helper on passenger trains occurs only where the train is so heavy as to require doubleheading on the grade.

It has been customary under steam operation to make up the train to a maximum weight of 2,900 to 3,250 tons, according to weather conditions, behind the engine and handle it by a Mallet road engine and a Mallet helper over the division and in addition a Mallet pusher up the 1.5 and 2 per cent grades, or three engines per train. All of which are of the latest compound type fitted with mechanical stokers and superheaters. They weigh about 370,000 pounds on drivers and 540,000 pounds total, including tender, and are estimated to have a tractive power of about 85,000 pounds. Tonnage trains are handled normally at a speed of from seven to eight miles per hour on the grades, but on account of the ventilating conditions, speed is reduced to six miles per hour in the Elkhorn Tunnel. It may be said that the tunnel is equipped with the Churchill plan of forced ventilation, which consists of blowing air through annular nozzles at the tunnel portal in the direction of the upgrade movement and at a slightly greater velocity than the speed of the train, thus blowing the smoke from the head of the train, and insuring that the smoke from the rear engine does not reach the front engine during the tunnel movement. It will, of course, be seen that because of the slow speed in this tunnel and because of the fact that it is single track, a very serious restriction in the capacity of the line occurs at this point and occasions frequent congestion and delay.

The decision to electrify was made about two years ago and the design and construction work placed in charge of the writer's firm as consulting engineers of the company. The question of a proper electric system was given especially careful study because of the difficult physical conditions and the unprecedented heavy haulage requirements. It was readily seen that an electrified third rail along the tracks was not practicable under the local conditions and that some system using an overhead collector would be required. This narrowed down the problem to a decision between the high-tension direct and the high-tension alternating current systems. Analysis of costs, both first and operating, as well as the consideration of the local operating conditions, indicated that the single phase alternating current system was the one that should be adopted. Attention might be called here to the fact that these heavy trains require enormous power for their movement, which in turn means large currents to be collected if the potential is low, but which is effected with much smaller currents if a system with the maximum allowable potential be used. The practical difficulties of collecting large currents from an overhead wire are well-known, the adoption, therefore, of a high trolley voltage is a logical solution of this problem. Electric braking down heavy grades, accomplished in a simple manner, is another attractive operating feature of the system adopted.

In working out the details of the installation a number of novel features were introduced, notably in the adoption of three-phase motors on the locomotives in connection with single phase current delivered to the locomotives. The required three-phase current for the motors is produced by a "phase converter." This is, essentially, a two-phase induction motor with a short-circuited or cage-wound revolving part, the stationary part having two windings with phase relations at right angles, one of which is connected across the line and serves to drive the motor and the other producing a current at right angles to the line current, thus giving two-phase power which, through connection with the transformer, is converted into three-phase power in the usual way. By this ingenious arrangement all the advantages of single phase transmission and a single trolley wire are obtained with the peculiar advantages, for this special service, of the three-phase motor. This motor is an unusually rugged piece of electrical machinery requiring no commutator and having high weight efficiency, or capacity, for given weight and dimensions. It has, however, constant speed characteristics, which are not desirable in some kinds of railroad operation, but which, for this particular service, have important advantages in respect to maintaining certain predetermined and limited train speeds irrespective of the loads. Furthermore this type of motor has the valuable characteristic of automatically returning regenerated current to the line on the down grades, this being effected without additional machinery or complication when the predetermined running speed is slightly exceeded during the coasting period.

The electric installation comprises the equipment of 29 route miles of main track, or 97 track miles total, with an overhead trolley wire operating at a working voltage of 11,000. A power house has been erected at Bluestone, a central point on the line, which contains three single-phase turbo-generators, each of 10,000 kw. rating for the load conditions, and the usual electrical and mechanical appurtenances, all of the most approved type. Current is generated at 11,000 volts pressure and stepped up to 44,000 volts for transmission to four substations along the line. These substations contain static transformers which lower the voltage to 11,000 for delivery into the trolley.

The overhead structures employed to support the trolley wires embody a number of novel features in respect to the use of tubular pole bridges, the poles being reinforced by rod guys on the outside of curves. This type of structure is simple, light, and relatively inexpensive and presents a minimum obstruction to view along the tracks. Of course, all structures, wiring and attachments have been carefully calculated for the maximum stresses which may occur from temperature change, the accumulation of ice and snow, effects of wind, etc. The insulation of the trolley line has been carefully designed to obtain at all places double insulation to ground.

Twelve locomotives have been provided for the service; each locomotive consists of two units or halves, each weighing 135 tons, giving a total weight of 270 tons for the complete locomotive. The frame of each half consists of two trucks connected by a Mallet type hinge and each truck has two driving axles included in the rigid wheel base, with a radial two-wheel leading truck. The bumping and pulling stresses are transmitted through the main truck frames and through twin draft rigging mounted on the main trucks at each end of the unit. The main trucks each carry two motors securely framed into the truck and both meshing into the same gear on each end of a jackshaft. These main gears are provided with crank pins from which connection to the driving wheel crank is made by side rods in the usual manner. By this arrangement the motors are carried on the main locomotive springs and are thus thoroughly cushioned against shock. Each half of the locomotive is provided with a cab supported on the trucks entirely by spring cushioned friction plates; the center pins carry no weight and serve only to maintain the cab in its proper position on the trucks. The cabs contain all current controlling and transforming apparatus, air brake pumps and reservoirs, with the usual appurtenances for the locomotive operation.

Each locomotive is equipped with eight three-phase induction type motors with wound secondaries for four and eight pole operation. There are two running speeds for the locomotives, namely, 14 and 28 miles per hour; for lower speed all motors are connected in parallel with the eight pole motor combination and for the 28 mile per hour speed they are connected in parallel but with the four pole combination. The motor voltage is 750, being reduced from 11,000 trolley voltage by transformers. In starting the locomotive variable resistance is inserted in the motor circuit by means of liquid rheostats; one of these is provided for each motor and is arranged to control the current by varying the height of the liquid by means of pumps. This liquid is kept constantly circulating to prevent excessive heating and is also passed through a cooling tower consisting of a series of trays arranged so that the liquid will flow over them in a thin sheet and thus be cooled by air from the same ventilating fan which is used for cooling the transformers and motors. The capacity of these rheostats has been made unusually great in order to meet the abnormal starting conditions; the rheostats are furthermore capable of operating the trains at one-half speed over the entire division, if necessary. This, in effect, gives a third operating speed which may be useful at local points.

The main dimensions of the locomotives are:

Length over all	105 ft. 8 in.
Rigid wheel base	11 ft.
Truck wheel base	16 ft. 6 in.
Diameter of driving wheels	62 in.
Diameter of pony wheels	30 in.
Weight on drivers	220 tons
Total weight of locomotives	270 tons

The drawbar pull varies from a maximum of 114,000 pounds during acceleration at the 14-mile per hour speed to 86,000 pounds when operating at this speed uniformly on a one per cent grade, but on a recent test the locomotive has developed a tractive effort in excess of 170,000 pounds, indicating, however, a coefficient of adhesion which cannot be assumed in practice. The maximum guaranteed accelerating tractive effort per locomotive is 133,000 pounds.

A valuable characteristic of the three-phase motors adopted is their capability of safely exerting full tractive effort for a considerable time while standing, the importance of which will be seen when it is remembered that the trains hauled are generally over one-half mile in length, and in the case of an empty train, three-quarters of a mile long. In starting this very heavy and long train there is sometimes difficulty in getting coincident action between the head and rear locomotives and thus it is especially important that both locomotives may be able to exert their full tractive effort for an appreciable time to take care of delays in getting full action and step. The motors in question have been designed to permit of full load current for five minutes standing.

At the present writing the heavy grade of this electrification, from North Fork to Flat Top yard, has been in operation for the past three weeks and the results forecast the entirely successful operation of the service as a whole in accordance with the expectations of the designers and the company. The movement of these very heavy tonnage trains has been electrically effected with ease and smoothness; the trains accelerate promptly and without shock or jerk to their running speed of 14 miles per hour on the heavy grades and it has been found that the full trains can be smoothly controlled by one head engine on the 2.5 per cent down grade by electric braking alone and at a uniform speed slightly above that of the regular running speed. The acceleration of one of these heavy trains is impressive as regards the amount of power required. Preliminary tests indicate the development of as much as 11,000 horsepower per train while getting into motion and operation at uniform speed up the grade requires 8,000 electric horsepower to be delivered to the train, but as far as the writer is aware no such amount of power has ever before been developed on a single train, either steam or electric, in regular service.

The electric apparatus for power house, substations and locomotives has been furnished by the Westinghouse Electric Company, and required much difficult development work by that company to be brought to such a degree of perfection.

PENNSYLVANIA ELECTRIFICATION.

The Philadelphia electrification on the Pennsylvania road is another important trunk line railway electrification which has been under way for the past two years and is now almost completed. It comprehends only suburban passenger train movement on the four-track main line from Philadelphia to the West, and does not include electrification for through passenger trains or for freight. Its primary purpose is to relieve congestion at Broad Street Station, Philadelphia.

The Broad Street Station is of the stub end type, with sixteen tracks approached by six main line and three yard tracks on an elevated railroad from West Philadelphia, at which point the main line routes divide for New York to the north, for Washington to the south and for Pittsburgh to the west. The station accommodates through passenger trains and, in addition, an extensive suburban movement over six different routes. The growth of all business in recent years has been such that the limit in capacity of the station has been reached and many plans have been formulated and discussed for relief by physical enlargement of the station and its approaches, or by rerouting movements. All of these plans involve extensive reconstruction and would require much time for their accomplishment so that a more expeditious method of obtaining relief was desirable. The possibility of employing electric traction for the purpose was investigated by committees consisting of operating officials of the road and their recommendation has resulted in the adoption of an initial program for this form of traction on the one of the suburban lines which promised to effect the greatest relief.

The cruicial point in the operation of the terminal is at the junction between the six approach routes with the sixteen station tracks at the interlocking cabin immediately west of the station. Congestion at this point is due to the regular scheduled train movements, the shifting back and forth from one track to another of cars and drafts, and the movement of empty power. By electrification, which permits the substitution of motor car trains for those hauled by locomotives, a certain number of movements are eliminated; for instance, it will not be necessary to provide for any light engine movements either coupling to an outbound train or for the road engine which has brought this train into the station and must follow it out on the return movement; furthermore, there will be some gain due to the quick acceleration of electric trains and to the shorter length of track occupied when the steam locomotive is omitted.

The most important suburban service is that on the main line west to Paoli, twenty miles out, and this service, therefore, has been electrified to furnish the greatest relief. It is estimated that during the rush hours the relief secured will be from 17 to 19 per cent in this particular service and for the station as a whole will be equivalent to the relief accomplished by reducing the total number of trains by about 8 per cent. This relief should, therefore, be sufficient to take care of normal growth of business even in bad weather, for the next four years and the period of relief can be further extended by electrification of the remaining suburban lines if the trial of this initial service should meet expectations.

The estimates under electric operation indicate that there will be sufficient saving over steam operating costs to pay interest on the investment which, of course, includes the most expensive portion of the work, in that the entire Broad Street Terminal with elaborate yard and restricted property lines and approaches thereto form a part of the construction required for a relatively small amount of train service. This result under the circumstances is not unfavorable, inasmuch as it means that practically speaking the increase in capacity can be made to pay for itself, whereas increase in capacity by a physical enlargement would give no direct return upon the heavy investment. There are, of course, other contingent advantages of electrification, such as higher speed of trains, more punctual service, especially in bad weather, and more cleanly and attractive conditions for the traveling public. But, as before stated, the electrification has been undertaken solely as an emergency measure to effect quickly a station relief which was greatly needed.

The electric system adopted for this installation is the single phase, alternating current system, using overhead contact wires supported from catenary cables, current being supplied to the trolley wire at 11,000 volts. Careful analysis and estimates covering all available systems led to the conclusion that a system using a very high voltage overhead contact wire and one which eliminates moving machinery in substations for the supply of power is most suitable and also the most economical both from the standpoint of first and operating costs. In arriving at the conclusions primary importance was also attached to possible future long-distance through electric operation over the entire divisions affected, rather than to the present requirements of short suburban electric service.

The fact that the New York Terminal is operated by the third rail direct current system does not constitute a serious objection to the use of the single phase system at Philadelphia and for main line extensions to connect with the present New York electrification for the reason that the mercury arc rectifier has now been developed and tried out on Pennsylvania equipment, the railroad having been co-operating with the manufacturers in the development of this apparatus for the last two years, to the point where it can be safely said to be available for use on electric locomotives. By adding rectifiers, transformers and control details to the present locomotives in New York, through operation to Philadelphia can be conducted with the single phase system.

The character of overhead construction adopted has followed a study of existing electrifications both here and abroad and the erection of an experimental section of the line with various forms of construction to determine the practical advantages, both from the standpoint of cost and especially to furnish the least obstruction to the view of signals along the tracks and reduce the unsightliness of the structures as far as practicable.

The line is of four tracks and used not only for suburban service, but for through passenger trains and for freight. The suburban service is confined to the two outer tracks, but must be occasionally crossed over to the middle tracks and for this reason and to increase the reliability of operation in emergencies it was decided to equip each of the tracks with a contact wire.

The interesting and novel features of the construction are in the use of tubular steel poles guyed on curves by two back guy rods and bridged between by cross catenary wires to carry the longitudinal catenary contact wires. As this line is equipped with a very complete system of automatic block signals, the bridges for these signals, which occur at intervals of about half a mile, have been designed to act as anchor bridges for the longitudinal catenary system. In order to increase the visibility of signals and to secure a type of signal having the minimum amount of mechanism on the bridges, a novel form of position light signals has been developed by the signal department of the railroad company. These signals consist of rows of lenses back of which are placed separate small electric incandescent lights mounted in front of an opaque screen background and hooded to concentrate the light, so that beams of light are projected and these produce "position" signals, as in the case of semaphore arms. The shifting of the lights from a vertical beam, indicating "safety," to the horizontal beam, indicating "stop," as well as to the intermediate position, indicating "caution," is accomplished by the switching of current on and off the respective groups of four lights which constitute the beams.

The cross catenary bridges are located 300 ft. apart and the poles carry one 44,000 volt single phase alternating current transmission line on each side of the outer tracks and a duplicate 2,200 volt signal transmission line.

The longitudinal catenaries consist of the usual form of steel messenger wires suspended to the cross catenary through insulators and from which are hung by bronze fittings a secondary messenger; from this latter the trolley wire is flexibly supported by bronze clips. The construction is designed for a maximum amount of flexibility and for the elimination of hard spots which may cause sparking at the contact when running at high speed. The 44,000 volt transmission current is stepped down in three static transformer substations along the line and fed into the trolley wires at 11,000 volts, from which it is collected by the pantagraphs on the motor cars of the trains.

The motor cars, of which 93 have been provided, are the standard MP-54 suburban steel passenger cars of the road. These cars are 54 ft. 6 in. long over end platforms and are lower over all than the standard main line passenger car, being 13 ft. only from the rail to the top of the roof. The seating capacity of the cars is 68 passengers. It will be noted that the cars are provided with end vestibules so arranged as to form a motorman's compartment at the head end of the train.

Each car is equipped with two Westinghouse single-phase, single-reduction geared motors mounted on one truck. These motors are of the series repulsion type and have been specially designed for this service and have a capacity of 225 horsepower each on a one hour rating. By special designing these motor cars occupy a minimum amount of space and have been mounted on a truck with 38 in. diameter wheels. This has not required any change in the height of the car floor or any reduction in the strength of the floor framing to secure the necessary clearances. Each car is equipped with one pantagraph collecting current from the overhead wire, a static transformer to reduce the current to the voltage required by the motors and the Westinghouse multiple unit electro-pneumatic control, also the usual appurtenances of motor driven air compressor and air brakes. Erection of all electrical apparatus has been done by the Motive Power Department at Altoona.

It should be mentioned that the equipment of this line has not included the building of a power house. Inasmuch as the amount of power required was not very great it was found desirable for the present to purchase the requirements from an existing power plant and a contract has therefore been entered into with the Philadelphia Electric Company to furnish single phase alternating current power at 13,200 volts at the main substation of the railroad company adjoining the line at Gary's Ferry, Philadelphia; at this point the power is stepped up to the transmission voltage, 44,000, for distribution over the line.

Time does not permit the going into details of the construction but it might be said that there has been some specially difficult work in the design and installation of the transmission and trolleys on the Terminal Division where there is a great complication of tracks, grades, curvature, etc. Complete operation into Broad Street Station is expected to take place at the end of May.

General statistics of this installation are as follows:

Route miles	20.3	
Track miles	86.1	
Grades, maximum	1.6	per cent.
Average westbound grade	0.55	per cent.
Per cent of line on curves	50	per cent.
Sharpest curve	4	degrees.
Number of trains per day (both ways)	84	
Average number of cars per train	3.25	

Maximum number of cars per train	7
Number of stops	19
Schedule speed, including stops	24 m. p. h.
Maximum speed	70 m. p. h.
Energy required (1 hr. peak)	3750 kw.
Number required (all motor cars)	93
Material	Steel
Length over all	64 ft. 0½ in.
Length—inside	53 ft. 7⅝ in.
Width over all	9 ft. 11½ in.
Height—rail to top of roof	13 ft. 0 in.
Seating capacity	68-72
Weight	118,600 lbs.
Weight, body	48,555 lbs.
Trucks (two) excluding motors	31,800 lbs.
Motors, with gears and gear cases	14,000 lbs.
Of all other equipment	24,245 lbs.
Total (without passengers)	118,600 lbs.

NEW YORK CENTRAL ELECTRIFICATION.

By Edwin B. Katte.*

The most interesting thing about electrification to railroad men at the present time is the first cost and here the comparison with steam operation is most unfavorable. For example, a modern steam locomotive costs about $25,000, and an electric locomotive of the same capacity will cost about $45,000; and that is not all, the cost of the power station, transmission lines, substations and working conductors must be added, which will bring the equivalent cost up to about $110,000, more or less, depending upon the system adopted and the character of the service. Hence, there should be a large saving in operating costs to cover the increased fixed charges, or there must be some other good reason for incurring the additional expense.

The New York Central Railroad Company electrified its lines into Grand Central Terminal because it had a bad four track tunnel condition to deal with at the most congested point of traffic. After electrification was decided upon, a very comprehensive scheme of improvements followed, which has cost in all, something like one hundred and twenty millions of dollars, resulting in radical changes in the movement and operation of trains. It is for this reason that a direct comparison between the former steam and the present electric operations is impossible. However, some general comparisons can be made, based upon rather broad assumptions.

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*Chief Engineer, Electric Traction, New York Central R. R. Edwin B. Katte is a son of Walter Katte, one of the charter members of the Western Society, whose account of its founding appears on page 339.

The average cost per locomotive mile derived from a large number of records of steam locomotives in all classes of service has been found to be about 26 cents per mile, including fuel and supplies, maintenance, repairs, and engine house expenses. A similar figure for electric locomotives operating in and about New York City can be shown to be about 21 cents per mile, but when fixed charges are added, the comparison becomes 30 cents for steam locomotives and about 60 cents per mile for electric locomotives. This comparison is only approximate and open to criticism because of the fact that conditions in New York permit but an average of 85 miles per day for electric locomotives, while the steam locomotives are averaging about 150 miles per day. Further, many assumptions too numerous to describe in this brief discussion were necessarily made, which would preclude the acceptance of these figures as a direct comparison of facts, but which are sufficiently accurate to indicate the tendency.

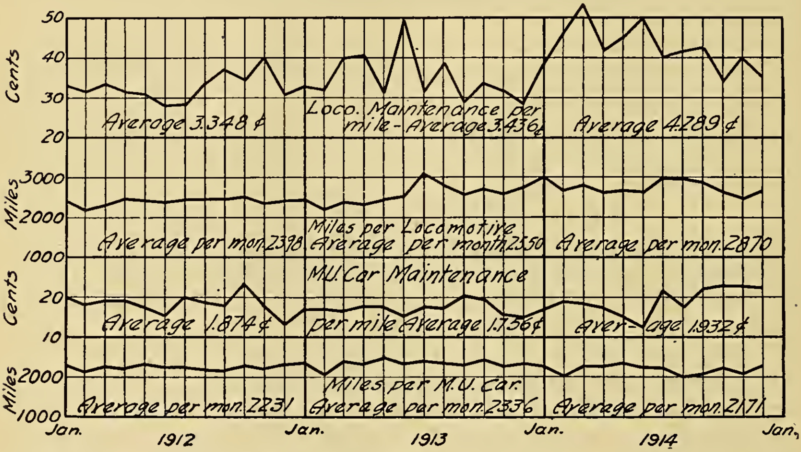
The electric locomotive service in New York and vicinity includes switching in yards and terminals, hauling shop trains about six miles, and a main line express service on one division of 34 miles and another division of 24 miles. The average cost for maintenance, including inspection, repairs, renewals, cleaning and painting varies from month to month, but the average covering a period of eight years is not far from 3½ cents per mile. The maintenance during the past year has been about 4 1/3 cents per mile. The increase was caused by the renewal in one year of driving wheel tires on the first 35 locomotives purchased. Fig. 1 indicates the variation in cost per month for the past three years.

The suburban service in the vicinity of New York City is handled by multiple unit trains consisting of from two to eleven cars, with trailers used in the proportion of two motor cars to one trailer on trains having easy schedules. Maintenance, including mechanical and electrical repairs, inspection, renewals, painting, etc., excluding only sweeping and window cleaning, has averaged somewhat less than two cents per car mile. This variation from month to month is also shown in Fig. 1.

The working conductor used by the New York Central Railroad Company is a special type of underrunning third rail, and is believed to afford greater protection from accidental contact than any other third rail. Its chief characteristics are, first, a wooden sheath enclosing the live third rail, except on the bottom or contact surface, and second, an insulated support so hung as to afford flexibility to prevent strains due to the up and down movement of the supporting ties under traffic. The cost of maintaining this protected third rail is naturally higher than for the usual type of third rail, and the large amount of construction work in progress adjacent to the third rail has increased the maintenance cost above normal conditions. The average cost has been about $26.00 per mile, per month, on the main line and $40.00 for yard and terminals, including track bonding and cable connections, both positive and negative.

The cost of maintaining the New York Central Railroad's cable system can be of little comparative value, because of the great diversity of its character to meet unusual local conditions. Lead covered, paper insulated cables are used in underground tile ducts. Steel wrapped, varnished cambric cables are used in iron pipes on the Park avenue viaduct; armored, lead covered, rubber insulated cables are laid under the Harlem river, while bare copper, aerial cables supported on steel poles are used in the outlying and less congested districts. However, as a general statement, it may be said that the cost of maintaining the three phase A. C. lines is about $8.00 per circuit mile, per month, and the direct current cables cost about $13.00 per cable mile.

Fig. 1. Operating and Maintenance Cost of Electric Locomotives and M. U. Cars. Also Average Miles per Month per Electric Locomotive and M. U. Car.—N. Y. C. & H. R. R. R., Electrical Department.



Note—The equipment being comparatively raw, operating costs are not average for the life of the apparatus. The low mileage is due to short car runs and the switching service in which many of the locomotives are engaged.

The cost of electric current varies considerably with the prices paid for coal, which in New York average from $2.50 to $3.00 per short ton. Also the fact should be noted that power stations in the vicinity of New York City are operated on three eight-hour shifts, in place of the more common twelve hour shifts. The cost of eleven thousand volt, three phase, 25 cycle current measured at the bus bars of the Port Morris Power Station averages between 0.45 cents and 0.50 cents per kilowatt hour for operating labor and materials.

Fig. 2. Train Minute Detention Due to Electric Operation for the Year 1914.—N. Y. C. R. R., Electrical Department.

	TRAIN MINUTE DETENTION.																								MILEAGE			AV. MILES PER M. DET.			
	Electric Power Trouble							Electric Locomotives							Multiple Unit Cars.									Total for all Causes	Loco's.	M. U. Cars.		Loco's	M. U. Cars.		Total for all Causes
Month	Power Sta.	Sub. Sta.	Trans. Line. 11,000 V.	Trans. Line. 600 V.	3rd Rail	2200 Volt Signal Line	Total	Fuses	Contactors	Reversers.	Misc. Elec.	Brakes	Misc. Mech	Total	Fuses	Contactors	Relays	Control Jumpers.	Misc. Elec.	Brakes.	Hot Boxes	Misc. Mech	Total		Total	Electric Zone	Total	Total	Elec. Delays	Mech Delays	
Jan.	–	11	–	–	5	–	16	36	18	–	86	5	124	269	–	13	–	–	27	21	5	43	109	394	188,314	459,989	475,607	700	11500	6893	1685
Feb.	–	–	157	–	–	35½	192½	21	4	22	60	8	193	308	2	–	7	5	76	26½	–	35½	152	65½	166,740	409,701	423,680	541	4552	6834	905
Mar.	–	–	47	–	–	3½	50½	–	9	24	9	4	65	111	2	–	–	–	7½	41	22	40	112½	274	175,555	459,250	474,219	1581	48,342	4604	2371
Apr.	–	–	–	–	–	–	–	–	50	–	54	3	–	107	–	–	3	–	17	–	18½	9	47½	154½	164,136	462,703	478,300	1534	23,135	17,393	4158
May.	–	3	133	–	25	14	175	4	–	60	4	19	–	87	–	5	4	–	–	48	–	3	60	322	166,034	471,724	489234	1908	52,414	9593	2035
June.	–	–	260	–	6½	12	278½	–	–	10	65	–	14	89	–	–	–	–	2	32	95	3	132	499½	165,851	449,854	465,339	1863	224,927	3580	1264
July	–	12	–	–	–	194½	206½	5	32	–	9	7	19	72	–	–	–	3	18	–	16	13	50	328½	185,656	441,956	461,564	2579	21,045	15,916	1970
Aug.	–	–	–	–	3	70	73	–	–	–	41	–	37	78	3	–	–	–	–	6	–	13	22	173	185,659	403,266	420,018	2380	134,422	22,106	3501
Sept.	–	–	–	–	–	–	–	–	14	12	14	–	–	40	–	–	–	3	–	–	–	13	16	56	180,548	412,802	429728	4514	137,601	33,056	10,898
Oct.	–	–	–	–	–	13	13	5	6	–	113½	4	–	128½	–	–	–	–	12	–	–	7	19	160½	165,670	451,312	467,138	1289	37,609	66,734	3943
Nov.	–	–	–	–	–	–	–	–	39	–	83	9	13	144	38	–	–	–	25	–	22	9½	94½	238½	155,860	421,944	437,350	1082	6698	13,884	2487
Dec.	–	–	–	–	9	121	130	–	–	–	32	–	10	42	–	–	–	–	–	62½	–	–	62½	234½	166,230	458,451	474,426	3958	—	7591	2732
Total.	–	26	597	–	48½	463½	1135	71	172	128	570½	59	473	1475½	45	18	14	11	184½	237	178½	189	877	3487½	2,066,253	5,302,952	5,496,603	1400	19,457	9093	2169

Note—Locomotives—Number of detentions, 94; miles per detention, 21,981. M. U. Cars—Number of detentions, 108; miles per detention, 50,894. Does not include New Haven trains. Based on total mileage of locomotives and M. U. cars.

When fixed charges are added, the cost averages about 0.75 cents. The transmission of current to the substations, transforming in substations, the loss in the working conductor system and the addition all fixed charges will bring the average total cost of current, delivered to the shoes of equipment, to about 1.75 cents per kilowatt hour.

As a measure of the reliability of electric equipment, a comparison of the locomotive or car miles per detention is preferable to a comparison of the miles per minute detention, since the former excludes delays to following trains and other causes of delay in no way contributed to by the equipment. During the year 1914, the average locomotive miles per detention was 22,000 while the multiple unit cars averaged 51,000 miles per detention. The train minute delays due to electric power troubles totaled 840 minutes for the year. The aerial lines contributed most largely, namely 535 train minutes; the third rail caused 244 minutes delay, substations 25 minutes and the power stations have never caused a minute's delay during their eight years of operation. (See Fig. 2.)

The electric locomotives are of the latest type used by the New York Central Railroad in express passenger service. They have a speed of 60 miles per hour when drawing a 1,200-ton train. All axles are equipped with motors, each having a continuous capacity of 250 H. P., or 330 H. P. on the one hour rating; that is, 2,640 H. P. total. The locomotive is equipped with an oil-fired, flash type boiler having a capacity of 2,000 lbs. of water per hour for heating through trains. The complete weight of the locomotive is 132 tons, all of which is carried on the drivers, thus giving a draw bar pull of 66,000 lbs., assuming 25 per cent adhesion.

The multiple unit cars are of all steel construction, 60 feet long over buffers and weight about 57 tons. They seat 64 passengers each. There is one motor truck under each motor car, having two motors of 200 H. P. each. The maximum speed of the train is 54 miles per hour.

THE NEW YORK, NEW HAVEN AND HARTFORD ELECTRIFICATION.

By Wm. S. Murray.*

We are rapidly putting far behind us the days when the attitude of railroads was to sit by and watch some one or two other railroads experiment with electricity as a motive power. Indifferent interest has given way to the realization that these pioneer roads which have been using this new power in every form of railroad movement have developed a fund of data which entitles it to more than passing interest, and requires that they be keenly alive to the possibilities it may hold out in the matter of betterments to their own property.

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That a thing of any character has the right to live and improve is based entirely on whether it is founded on correct principles. In the early days when electrical movement was first introduced on heavy traction railroads, theory was strong and practice severely limited. The guiding principle upon which electrical men based their opinion that electrification had its proper place in the economic world, was that by its use certain savings could be effected that would justify the investment necessary to secure it. There was entirely outside of this, but indirectly an economic factor, the advantage accruing to the passenger in the form of a clean ride.

While I have, of course, been keenly interested in electrification that has been applied to other railroads, naturally the past ten years' association with the New Haven work, during which time over $15,000,000 have been expended in this department of betterment, has brought the real elements of its progress within very close range.

In June, 1914, the first New York, New Haven and Hartford passenger train was operated from Grand Central Station to New Haven over a four-track electrified route, 73 miles in length. Between New York and New Haven, measured upon a single track basis, there are some 500 miles of electrified line, of which 184 are included in yards and sidings. On these tracks today, every class of passenger, freight and switching movement is made, and electrical statistics are kept of all power house, line or equipment failures, a reference to them suggesting the features of electrical operation that require first attention for the betterment of service. These statistics of electrical operation will doubtless be available in the Franklin Institute Transactions in a short time.

A feature of electrification that at present is the most appealing to one who has given the subject some consideration, is in the matter of freight and switching movements. Since 1907 the New Haven Road has been operating its regular 100 per cent electric passenger service between Stamford and New York. But recently, experience with regard to electric movement in switching and classification yards, and more recently that with regard to freight movement on main line track, has indeed been a revelation in the possibilities of heavy electrical traction. For example, during the month of January past, on the New Haven over 40,000,000 ton miles trailing load were handled by electric locomotives, this total tonnage being made up of fast, slow and local freight movement. There is installed on all of the electric engines wattmeters to register the kilowatt hours of consumption. Records of these wattmeters indicate that fast freights require on the order of 34 kw. hours per train mile; slow freights on the order of 60 kw. hours per train mile; local freights on the order of 36 kw. hours per train mile. These figures being for trains varying in tonnage from 1,000 to 3,000.

Of interest also are the kilowatt hours per 1000 ton miles of trailing load. For fast freight the kilowatt hours per 1,000 ton miles are on the order of 30; for slow freight 30; and for local freight 85. I make mention of these figures only to illustrate this new and vast sum of information that is daily coming to us. The "watt hour constants" are of necessity average figures, made up of trains having varying weights and schedules, and yet the records from which they are taken admit of instant segregation into any class of service for which a constant is desired. The question that might be asked in looking at these constants is: What do they signify? And the answer is brief; an electrical ton mile as against a steam ton mile reduces the coal pile in a ratio of 1:2.

While our present freight movement by electricity on the main line is today limited both on account of the general depression in business, together with the fact that a full complement of electric freight locomotives is not yet at hand, a record of one day's movement of electric freight trains between Harlem river and Bridgeport shows 14 trains, 804 cars and a tonnage of 28,159. There is no question in my mind but that the greatest returns to be secured by electrification will be through freight movement.

While in the past we have appreciated the economies to be secured through electrification, in virtue of lesser expenditures required in fuel and maintenance of electric engines as against steam, there is fast coming to the front what might be called a more visualized economy in the reduction of expenses by effective savings in train miles.

Illustrative of the economic value of a "kilowatt hour" in its application to an electrification system, I quote from a part of a recent letter which had reference to the utilization of some 4,500 kw. of demand in connection with its application to the eastern section of our electrification zone. I would particularly draw your attention to the item of $49,275.00, which has reference to the economies to be gained by the double heading of freight trains operated between Harlem river and New Haven. This economy, and its automatic complement, the increase of track capacity, are the phases of electrification that are striking deep into the consideration of the steam operation railroad man.

"(1) The extension of the station contemplates, as you know, supplying a maximum single-phase demand of approximately 4,500 kw. This amount of power measured by train units, would permit the operation of twelve additional daily trains in fast freight service of average tonnage, or its equivalent in any other class of service between Harlem River and New Haven.

"(2) The number of kilowatt hours which would be consumed by the above twelve trains would be 17,500,000 kw.h. annually, and, as previously discussed with you, upon a coal ratio of 1 to 2 in electric and steam service and a basis of three lbs. per kilowatt hour and $3.00 per ton, an annual saving to the railroad company of $78,750 is indicated.

"(3) Further translating the above movement into engine miles, our log sheet records indicate that the number of engine miles required for the above movement would be 990, which multiplied by the difference in cost of engine repairs at 5 cents per engine mile, effects annual savings of $18,250.

"(4) The transfer of twelve daily trains from steam to electric service will permit a further extension of our present practice of 'double heading' trains in electric service, thus saving 450 daily train miles, which as shown by our log sheet will secure an annual reduction in train wages of 30c per train mile, corresponding to an annual reduction of $49,275.00.

"(5) A supply of approximately 3,000 kw. (average) to the New Haven end of the line will effect a further saving of $16,500 in transmission losses, as compared with the transmission losses of the same amount of power from Cos Cob Station; the above savings being based upon the conservative cost of 5 mills per kw.h. In explanation of the apparently large value of the saving in transmission losses to be effected by this small installation, it will be evident that its value is maximum when applied at the extreme end of the transmission system.

"(6) No tangible values can be assigned for the very important effect upon the regulation in line voltage at New Haven, which will be reflected in the cost and efficiency of operation in many ways.

"(7) The summary of the total savings as above, which will be effected is as follows:

Fuel	$ 78,750.00
Engine repairs	18,250.00
Engine and train wages	49,275.00
Transmission losses	16,500.00
	$162,775.00

If any criticism can be placed with regard to the matter of freight movement by electricity, I would say it would be in the matter of speed. The electric freight locomotives of the New York, New Haven and Hartford Railroad were built on specifications that permitted them to operate 1,500 ton trains on level track at 35 miles per hour. While the speed element, in as far as the New Haven service is concerned, may be entirely justified due to the very large ratio of passenger to its total service, thus permitting the freight trains to clear more promptly for passenger traffic, I would say that where the ratio of passenger service is less, the speed element for equal horsepower could be more valuably thrown into traction. For example, the New Haven locomotives have draw-bar pull characteristics that permit the operation of 3,000 ton trains by double heading. If these engines were reduced in speed by 35 per cent and their traction increased by the same percentage, 4,000 tons would be the resulting double header trailing load which in turn would effect a large saving in train miles were these engines to be operated on a property less subject to passenger movement.

Much valuable information has been developed in the past two years in connection with the handling of classification and switching yards by electric motive power. An idea as to the reliability of this class of service may be gained in saying that in 1,000,000 electric switch engine miles there has been but one failure.

The New Haven property includes in it two large switching yards: the Oak Point Yard containing 35 miles of track; the Harlem River Yard 25 miles. The introduction of the electric engine in these yards has increased the speed of the yard very greatly, and as near as I can gather from the yardmasters this increase of speed has been secured with a ratio of electric engines to steam engines replaced varying between 4 to 6 and 6 to 10.

Electricity in trunk line territory is now on a plane of consideration entirely different from the earlier days when it was new, untried and problematical. The future will see its agency playing a most important part in railroad competition.

While this paper has had particular reference to the New Haven and its increase of operation through the extension of its electrification zone, it would seem very inappropriate with so good an opportunity as this, not so say a word or two as to "system." I am willing to admit that I am a firm believer in the single phase system for trunk lines, the governing element in which, from an electrical standpoint, has been the transmission system. In a rigorous determination to adhere to this principle as correct for such a field, it has not been to gainsay the application of direct current in the territory where it rightly belongs; namely, where the governing element has been mass (trains under acceleration and breaking in close headway) in translation. As a citation of the two examples I would offer: (1) The electrification from New York to New Haven, and (2) the electrification of the New York subways.

In closing I would speak of two things which to my mind are most pertinent to the advance and successful utilization of electricity in the field of heavy traction.

The first is with reference to the mercury arc rectifier, and the second is in regard to effective electrical administration on the part of railroads electrifying.

Having reference to the mercury arc rectifier, I feel sure that it will be of interest to state that there has been in commercial operation on the New Haven Road a car taking power from the 11,000 volt alternating current overhead contact system, and converting it into direct current for application to its propulsion motors. This car has been giving a most successful service, and the problem of the production and maintenance of the vacuum tube, through the agency of which the alternating current is converted to direct, has been electrically and commercially solved. What are the possibilities accruing from such a result? This can be epitomized in the statement that, if the economies in the transmission system of the single phase system justified the utilization of a heavier and less efficient motive power, today we are in a position not only to secure the economies gained in this transmission, but also to operate beneath the contact wires of such a system the more efficient and lighter direct current apparatus. As a concrete and practical application of this result, the present alternating current motive power now in use on the New Haven will be increased 25 per cent by the application of the rectifier, and also permit it to enjoy simultaneously transmission and motive power facilities of the highest order of efficiency.

With regard to administration, past experience with the engineering, construction and operation of a trunk line property of the character of the New Haven road has indicated with force the necessity of a very complete understanding of the difference between the operation of a steam and an electric property. In my judgment there will be no necessity for any general change in the administration or organization at present observed in steam operated properties to effect proper electric operation, but upon the minds of higher officials in the steam roads using or contemplating using this new mode of motive power, the fact should be impressed that the methods pursued in producing a ton mile of any character, passenger, freight or switching upon a steam basis must be abandoned when the draw-bar pull comes from electricity. The error of holding a steam master mechanic responsible for an electric engine mile of any character is patent, and equally patent is the error of holding a steam railroad shop man responsible for the maintenance and repairs of electric engines. Like electric power houses and transmission lines requiring the proper electrical talent, essentially necessary to the success of proper maintenance and inspection of electric motive power, are the electro-mechanics inside and outside of the shop. Such an arrangement does not change but merely affects the splendid railroad organization and administration that has come down to us. A successful operating result after electrification has been applied, is entirely dependent on a clear understanding and observation of this real difference between steam and electrical operation.

THE C. M. & ST. P. ELECTRIFICATION.

By C. A. Goodnow.*

The Chicago, Milwaukee & St. Paul Railway Company is now engaged in the electrification of that portion of its main line to the Pacific coast between Harlowton, Mont., and Avery, Idaho, a distance of 440 miles. This project is of special interest because: (1), it provides for the electrification of four entire engine districts; (2), this work is being done to effect economies in operation on a single track line of moderate traffic and not to overcome congestion on a busy line now working to its capacity or to eliminate the smoke nuisance.

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*Assistant to the President, Chicago, Milwaukee & St. Paul R. R.

Between Harlowton and Avery this line crosses three mountain ranges, the Belt Mountains at an elevation of 5,768 feet, the Rocky Mountains at an elevation of 6,350 ft., and the Bitter Root Mountains at an elevation of 4,200 ft. There are several tunnels, the longest of which is the St. Paul Pass tunnel at the summit of the Bitter Root Mountains, 9,000 ft. long. The maximum grade westbound is 2 per cent for 20.8 miles on the eastern slope of the Rocky Mountains, while the maximum grade eastbound is 1.7 per cent for 24 miles approaching the St. Paul Pass tunnel. The hardest problem of this nature, however, is presented by the continuous 1 per cent grade for 44 miles, ascending the western slope of the Belt Mountains, involving as it does the necessity for special precautions to avoid overheating the motors while working at their maximum capacities for this long period of time.

Besides the yards at Harlowton and Avery, intermediate terminals are now located at Three Forks, Deer Lodge and Alberton. These terminals are all small and with the exception of Butte and Missoula, there are no towns of any importance within these limits. There is, therefore, practically no breaking up of trains as all traffic is through business. Including these yards and side tracks about 650 miles of track will be electrified.

Power will be purchased from the Montana Power Company. Owing to the ample supply of water power available and the low cost of construction, the unusually low contract rate of $0.00536 per kilowatt hour has been secured. By contracting for its power the railroad thus avoids expending directly the large amount required for the construction of power plants. To minimize peak loads it is probable that the duties of the train and power despatchers will be combined. In this way the spacing of trains can be best arranged to keep the peak loads down to the minimum. With the traffic existing on this line it is expected that this can be done without serious interference with the operation of freight trains.

To minimize the dangers of interruptions to the delivery of power a tie-in transmission system is being built by the railway to permit feeding each substation from two directions and from two or more sources of power. The transmission line is being constructed with wooden poles, will operate at 100,000 volts and in most cases will follow the right of way.

The Montana Power Company will deliver energy to the line at seven points between Harlowton and Avery. On the engine district between Three Forks and Deer Lodge, on which work is now under way, three substations are being built to convert the 100,000 volt, 60-cycle, 3-phase alternating current to 3,000 volts direct current. This is the first direct current installation using as high a potential as 3,000 volts and was adopted after observing the results secured with the 2,400-volt, direct current installation of the Butte, Anaconda & Pacific, which parallels the line of the St. Paul for a short distance west of Butte.

The trolley construction is of the catenary type, with two 4/0 trolley wires flexibly suspended from a steel catenary and supported on wooden poles with brackets on tangents and flat curves and cross spans on the sharper curves and in yards, the twin-conductor trolley consisting of two 4/0 wires suspended side by side from the same catenary by independent hangers alternately connected to each trolley wire. This permits the collection of very heavy current by reason of the twin contacts of the pantograph with the two trolley wires.

Contracts were let last year for 9 freight and 3 passenger locomotives for use on the first engine district, while 9 additional locomotives were ordered early this month for use on the second engine division from Three Forks to Harlowton. The passenger locomotives are designed to haul 800-ton passenger trains at a speed of 60 miles per hour on the level, or 35 miles per hour on a 1 per cent grade, and will be equipped with oil-fired steam heating outfits for heating the train. The freight locomotives are designed to haul a 2,500-ton train on all grades up to 1 per cent at a speed of approximately 16 miles per hour. This same train load will be carried unbroken over the 1.7 and 2 per cent grades with the help of a second similar locomotive acting as a pusher. At the summits of the grades, provision is being made to run the pusher locomotive around the train and coupling it to the head end to assist in the electric braking on the descending slopes. In addition to providing the greatest safety in operation, this will also enable a considerable amount of energy to be returned to the trolley for the assistance of other trains and reduction in the power bill. The electric locomotives will have sufficient electric braking capacities to hold the entire train on the down grade, leaving the air brake equipment for use in emergencies or when stopping the train.

At the present time work is being actively pushed on the engine district between Three Forks and Avery, 113 miles, crossing the summit of the Rocky Mountains, and it is expected that this will be ready for operation next October. Work is now also being started on the engine district from Three Forks east to Harlowton and it is planned to start work on an additional district each year until all four are completed. The contract with the electrical company provides that the entire 440 miles be in electric operation by January 1, 1918.

Several important economies are expected from the electrification of this line. In the first place this is the first time an entire engine district has been electrified, permitting the complete substitution of electric for steam locomotives between the terminals. In other installations throughout the country only a portion of a division has been electrified, resulting simply in a shortening of the steam operated engine district. With the present schedules enforced with train employees this has not enabled the savings to be secured which will result from the electrical operation of the entire engine district. Furthermore, with the electrification of four adjoining engine districts, it is planned to change locomotives only at the second terminal or at Deer Lodge. The crews will be changed at the intermediate terminals, Three Forks and Alberton, but there will not be the delay incident to the present methods of operation. It will be possible to abandon these intermediate terminals with the exception of a small amount of trackage on which to set out bad order cars, hot boxes, etc. It is also expected that with the low contract price for power which has been secured, a considerable saving will be made over the amount now expended for fuel. From these and other savings expected, it is anticipated that this expenditure will yield a very attractive return on the investment. If this is realized, it is possible that electrification may be extended from Avery across the Cascade Mountains to Seattle and Tacoma, a total distance from Harlowton of 850 miles, but not, however, in the near future.

DISCUSSION

President Jackson: In the past we have had many discussions relating to various systems by which electricity may be applied to the electrification of steam railroads, but on the whole these discussions have accomplished relatively little. However, this evening's discussion of operating results obtained from actual experience in the electrification of steam railroads, by men who have been actively connected with the operation as well as the construction, has been not only interesting but very valuable to the profession.

Regarding the operation of the New York Central electrification at New York, I will take the liberty of saying a few words as to my impressions of this particular work after going over the New York Central electrified zone a few months after all passenger trains were being operated electrically.

Probably the most noticeable feature of that installation was the remarkable smoothness with which everything was operating, as if the whole installation had been in use for years instead of months. I have found this to be the case with several main line electrifications both in the United States and Europe, and believe this has been the result experienced in most main line electrifications.

We have a very unusual gathering of men here who can tell us from personal experience, results obtained from steam railway electrification and also of the results that may be expected of future installations.

Fortunately these men can attack the problem from three different angles; the electrification engineer, the steam railroad engineer and the unprejudiced investigator. Accordingly I shall call upon Messrs. E. H. Lee, Jesse Holdom, C. S. Churchill, W. F. M. Goss, J. C. Mock, E. M. Herr and B. J. Arnold.

E. H. Lee, M. W. S. E., Vice-President and Chief Engineer, C. & W. I. R. R.: You all understand that I make no profession of a comprehensive knowledge of electrification or of its application in the operation of steam railroads, but I fully appreciate this opportunity of hearing this problem discussed, and think that the Society is especially fortunate in having papers from such representative men who are so well qualified to discuss this aspect of the subject. Nobody can doubt that electrification is a great problem; nor can they doubt that electrification is coming. As a steam railroad man I should hesitate to predict that it will not come into general use in the future. However, there is one broad principle that should apply. The most primitive method of freight transportation is probably that of carrying loads on mens' backs, as is still practiced in China. On a trip several years ago I was particularly interested in freight transportation method in the southwestern portion of the country. I noted that man power had been superseded by burro-train and when the requirements became excessive the burro-train was superseded by the mule wagon; then the single wagon was displaced by a three-wagon train. Further along I went into a part of the country where the wagon train of that description was not equal to the demands, and that method was about to be displaced by a gasoline or oil driven motor truck, to be followed by six or eight trailers. Now this all demonstrates the broad principle to which I refer. This same principle was brought out in a discussion which I recently heard between men especially qualified on the question of electrification; that the same reason for the improvement in other methods of freight transportation will determine the use of electricity in displacing steam, or will indicate that such use is not warranted, namely, the relative density of traffic. It seems to me that in reckoning up the possibilities and the needs to warrant such a change, we must get down to bed rock.

The President said that I am "from Missouri." It behooves us all to be from Missouri. We should demand to be shown. If the change is to come, it should be brought about principally by reason of economy. As engineers we must consider the problem both as to whether the change is warranted by other conditions, and whether it will pay.

Judge Jesse Holdom, Chairman, Chicago Association of Commerce Commission on Smoke Abatement and Electrification of Railway Terminals: Mr. President and friends: It is gross flattery to ask a man who knows as little as I do about any kind of engineering to talk to this very distinguished body of engineers. For the past four years I have been instructed a good deal in this line by my brother, Dr. Goss, in the work of a committee of which he and I happen to be members, he being its Chief Engineer. The final analysis of the committee's problem is the necessity and feasibility of the electrification of the railway terminals in the city of Chicago. During these four years I have heard a great deal of discussion of this problem pro and con, and the conclusions of the committee are not yet quite reached. Naturally the railroad men have a great deal of faith in their old, well-tried and reliable steam engines, and I do not blame them. She is a dirty smoky thing but if she were abolished the air pollution would not be perceptibly improved. I do not think anything ever invented did as good, steady and reliable work as the old smoky steam locomotive, and I have noticed that the genius of the best engineers and mechanics have been bended to one thing, that is, to try and invent some other unit of power that will do the same work and do it as well as the old-time steam locomotive, and if they ever get anywhere near to accomplishing so much as this very much despised smoky locomotive with a new unit of power, I am quite sure the good old faithful steam locomotive will have to go to the rear for all time. One among many difficulties in bringing about electrification is, as my brother Lee says, will it pay? Is it an economical possibility? I have no doubt that all of the terminals in this big city would soon be electrified if the roads could get away from the heavy burden of the first cost. This is a bugaboo the roads cannot escape. Just think of scrapping all of those useful, smoky locomotives that cost so much money! It is a tremendous problem, and yet I think in the evolution of time the railroads—passenger, freight and suburban service—will all be operated by electricity, although it may be a hundred years to the time of the fruition of these hopes of today.

Electrical transportation is very attractive to the traveling public; it is comfortable, clean and pleasant. When I look around me and see all of these engineers, and think of others who are not here, I feel sure that when this problem is possible of solution it will come through the ingenuity of these men, and come it will when it is financially possible. The greatest difficulty, as I see it, is the financial consideration. We cannot have changes of so revolutionary a character unless the money is available to pay for them. The railroads must have the money in order to get the new equipment which electrification will necessitate.

It has been a great pleasure for me to be here this evening and listen to Mr. Gibbs and Mr. Katte and others who have accomplished so much in the line of the electrification of railroads. Theirs is grand work and the result of their genius and labors will be their lasting monument.

Mr. C. S. Churchill, Assistant to the President, Norfolk & Western R. R.: Mr. Gibbs has explained this matter so fully that it seems to the speaker he can add very little to the former's statements. Perhaps it might be of interest to say something about the beginnings. The proper beginning was very well described by Mr. Lee. It consists of finding out whether the business conditions are such as to warrant any such expenditure of money as electrification requires. This investigation was started by the Norfolk & Western Railway in 1905. The reports on possible economies were not then satisfactory; they did not show any assured savings. In those days the principal savings that the electrical manufacturers could suggest were those that might result from a reduction in the number of men required, whereas now we know that the services of no men are saved by the motors, because two men are required with each of them; and the original proposition was, therefore, not acted upon. The Norfolk & Western Railway was, consequently, obliged to investigate this subject from a different standpoint entirely, such as economies resulting from savings in coal consumption, which have been found, as just stated, to be on the New York, New Haven & Hartford Railroad, as 1 to 2 in favor of electric operation; in increasing the capacity of the railroad itself; also safety of operation, with resultant decrease in cost. The increasing of the capacity of a line is of great value and was an important element in our case. Mr. Gibbs has brought out this point in calling attention to the fact that coal trains make a speed of about 7 miles per hour with steam locomotives on a 2.0 per cent grade, whereas with an electric locomotive the speed is 14 miles per hour. In order to secure in detail an estimate of economies, the Norfolk & Western Railway kept, for a long period of time, a log record of all freight trains in that 30-mile district described, and also kept a record of all engine repairs, consumption of fuel and supplies and all other costs. It is a hard thing to secure this data and it is seldom accomplished on a district as small as 30 miles. It is difficult to segregate the expenses and it is possible only by keeping full reports by trips. On a grade of 2.0 per cent with three Mallet engines on each train, it is surprising to note what a tremendous loss of time occurs on such a trip, stopping at one time to clear the fires, again to get water, again to coal, again for signals, and short delays from other causes, and so on. These delays multiply so that those steam locomotives make but one trip per day, while the electric motors will make two or three trips per day. From this statement there will be seen at once the main reason for the economy in that type of operation. The displacing of thirty-three Mallet locomotives by eleven electric motors, which will be the result on the Norfolk & Western Railway, brings clearly to mind where the economies will come in. All this indicates, without any further explanation, how such a problem should be approached by any one interested in this subject. The density of the traffic is, after all, the important factor. The fact that 60,000 tons per day was the basis of our estimates is practically a statement that anything much less will be unprofitable for electrical operation on such a railroad district as is being electrified on the Norfolk & Western Railway.

Both Mr. Gibbs and Mr. Katte have pointed out other reasons for electrification than a direct saving of money. Indirect savings of importance may be found at important terminals in many places, but the estimating of either direct or indirect economies should be proceeded with on lines similar to those adopted by the Norfolk & Western Railway, and if sufficient density of traffic of any kind exists the economies may be made up of those resulting from increased capacity of tracks, savings in time, savings in fuel and supplies, savings in repairs, and savings in various types of labor. But none of these savings can be even estimated without first segregating every item of cost under the existing methods of operation of the terminal or district of the railroad in question.

Now, gentlemen, it is well to think over that point very carefully, and remember, at the same time, that a railroad company cannot well approach this subject with the idea of securing real savings unless some such density of traffic already exists.

W. F. M. Goss, ASSOC. W. S. E., Chief Engineer, Chicago Association of Commerce Commission on Smoke Abatement and Electrification of Railway Terminals: Mr. President, members of the Western Society, and friends: First of all, I must congratulate the Western Society upon having been able to attract the attention of these "three wise men from the East," who have brought their message to us. Their presence and contributions make this a significant meeting, for there are none better qualified to speak on the subjects which have been presented to us than Mr. Gibbs, Mr. Katte and Mr. Murray. I am glad to have an opportunity to express my appreciation of their courtesy.

There is not much that I can say concerning the great problem which you would like to have me present. It happens that the report of the committee which I serve, dealing with the problems of smoke abatement and the electrification of Chicago's railroad terminals, is now in the hands of the printer, and until it issues I cannot speak. The fact that Judge Holdom, the distinguished Chairman of our Committee, sits by me, ready I am sure to pull my coat if I venture too far afield, naturally suggests caution.

I may, however, call attention to the significance of the work of the Committee, in the light of the descriptions this evening. The marvelous work which has been done in the electrification of the traffic of limited sections of certain great railroads, presents engineering achievements of the highest quality, but the work in the case of each road described is nevertheless a pioneer installation. When you couple that fact with the fact that of all the steam railroads in the world which thus far have entered upon electrification, the total number is less than the number of railway corporations which make up the Chicago railway terminals, the extent of the committee's problem becomes apparent. It is probable also that the number of electric locomotives required for the operation of the traffic of this city is in excess of the total number of electric locomotives which the world possesses today. It is certain that the track mileage making up the terminals of Chicago, which is comprehended by the plans of the committee, is much in excess of the world's total electrified trackage of steam railroad standards. With this understanding of the extent of the problem, and the fact that all locations have been studied, designs have been made, energy requirements involving an extensive and diversified traffic have been determined, and cost has been formulated, should satisfy the members of this Society that the four years which Judge Holdom and the sixteen other busy men who make up the membership of the committee have given to the preparation of their report, has been time well spent. The results of their work will soon be in the possession of the public.

J. C. Mock, Signal Electrical Engineer, Michigan Central R. R.: The problem at the Detroit River Tunnel is a little different from any presented tonight, in that we were changing from a floating equipment for handling traffic across the Detroit River to one of rail, and, of course, you could hardly conceive of its being handled by steam through a tunnel under the Detroit River, because at the time it was contemplated, the New York Central and the B. & O. had been successfully operating electric trains, and the Grand Trunk was just about to begin at Port Huron.

The Detroit River Tunnel is really a terminal problem; merely a switching from the terminal in Detroit to the end of the Canadian Division in Windsor. The grades in the tunnel are 2.0 per cent in one direction and 1.5 per cent in the other. We are handling about 1,500 cars per day, including about 180 passenger cars. Their tonnage, taking an average of both passenger and freight, is approximately 50,000 tons per day. The type of locomotive used is a little different from any shown tonight. It is geared type, four axles, with four motors, mounted similar to street and suburban cars. The first six weighed 100 tons, which is supposed to be about the limit of axle loading for standard track. The last four were increased 20 tons each. The reason for this is increased weight of passenger trains, because of steel coaches weighing from 600 and 800 to 1,000 tons. These on 2.0 per cent grade would require a little more tractive effort than one 100-ton locomotive could develop for proper handling. Many passenger trains were handled, as a matter of safety, with two locomotives, both ahead.

All freight trains of full make-up, of any tonnage above 1,000 are handled with one locomotive ahead and one behind. It is not considered safe, with the present equipment, to exert much more than 50,000 lb. draw-bar pull.

The operation has been very successful. The primary three-phase current is purchased from the Detroit Edison Company. A third rail, like that of the New York Central, is used to carry the 650-volt direct current. The total mileage is about 25; the freight haul is 3.6 miles, and the passenger haul is 2.8 miles. Passenger trains under a maximum speed of 35 miles per hour make the trip in average time of 10 minutes; freight trains under a maximum speed of 30 miles per hr. make the trip in average time of 20 minutes. All engines are changed from steam to electric as trains arrive to go through the tunnel. Total trains per day average about 50. The approximate watts per ton mile is 35.

E. M. Herr, President, Westinghouse Electric and Manufacturing Company: The last time I had the pleasure of attending a meeting of the Society I was in the railroad service, and having had sixteen years' experience among the engineers of the Society as a railroad steam motive power man, it might be realized that perhaps I appear before this distinguished audience with some embarrassment, as a manufacturer of electric machinery, but such are the changes in our great country. It has been with a great deal of interest that I have watched the development of the use of electric machinery on railroads.

I was very glad to hear the expression so freely given here tonight, that the engineers ought to be "from Missouri" when it comes to electrification. I agree with that idea, and as a manufacturer of electrical machinery, regard it as of prime importance, because if we get any electrical machinery installed where it ought not to be, the manufacturer is sure to hear of it, and it is of the greatest importance to us as well as to you and all your clients to be sure that the installation of electrical machinery is well considered and properly applied. It is interesting to note the development of the use of this new power in the transportation field. We are only in the infancy of it, and yet very notable progress has been made in the past ten years. It is just about ten years since the first installation of heavy traction work in railroads was made. I was talking to a friend recently, who is vice-president of one of our largest railroad systems, a man I know very well, and with whom I have talked a great deal about the use of electricity in main line traffic. Heretofore he has been very skeptical about the use of it, but I was much interested in hearing him say that one of his neighbors, he felt, had wasted a great deal of money in heavy grade divisions on a badly congested part of their line. Had he instead used electric locomotives he would have accomplished much greater economy for a less expenditure of money. I merely state this as an instance that our minds are changing, and the ability to use this force is advancing, and yet we are only in the infancy of its use. But above all, stick to your principles of being "from Missouri" as to its application.

B. J. Arnold, M. W. S. E., Chairman, Board of Supervising Engineers, Chicago Traction: You are so accustomed to hearing from me in connection with this city's terminal problems that I hardly think you want to listen to me tonight, and especially since the hour is late.

It was a great pleasure for me to see the secretary of the Commission on the Electrification of the New York Central Railroad here tonight. I note that he was called one of the "wise men from the East," and he certainly deserves that title, although he might be considered by some as almost too young to be credited with so much wisdom. I feel certain that he will not disappoint them. It was my pleasure to have been associated with Mr. Katte and Mr. Gibbs in the electrification of the New York Central Railroad—Mr. Gibbs as a member of the commission and Mr. Katte as its secretary. I want to congratulate them on having secured such splendid results.

At one time in my experience I was a steam railroad man and I thought then that I knew something about locomotives. Then, in 1888, I thought I could see that the electric railroad would be the railroad of the future, and since then have been more or less interested in that direction. During the development of the science of electrical engineering—involving the electric railroad, electric locomotives, electric cars, etc.—the steam railway men have not been idle in locomotive design by any means. They have come from the old type of locomotive to the Mogul, then the ten-wheeler or Decapod, then to the Mikado and finally to the Pacific and Mallet type. So the steam designers have been just as alert as the electric designers, and the problem now is the relative efficiency of the steam and electric locomotives, and as far as that is concerned, the steam locomotive is about as efficient as the electric locomotive, with the latter's essential accompaniments. There is always a question as to what is the special advantage in applying electricity to a certain part of any road. My experience with the New York Central Railroad indicated that the economies of electrification just about offset the interest on increased investment, and therefore electricity could not be chosen on the ground of economy. Therefore it usually resolves itself into a question of increased capacity.

So far as economy and operation are concerned, we were not in position in the early days of electric railroading to prove that the increased capacity would warrant the change, nor that by the use of electricity they could make more miles per day per locomotive. For several years after the electrification of the New York Central Company's terminal its electric engines were limited as to miles they could make daily, because of the short run. An enormous investment in power plants, substations and transmission lines was carried and charged against this small amount of mileage. So it was extremely difficult for anybody connected with that road to show that the change had effected economies, but it was easy to see that the change had greatly increased the capacity of the terminal. Only within the past few months has the service been extended to the points for which it was originally planned, and the economies should begin to show.

The New Haven Road, with which Mr. Murray is connected, had the same handicap for some years, but recently the road was extended to Hartford, and now there is mileage enough to begin to get the economies he cites in his paper. He indicated that certain economies are bound to be greater as the length of the division increases. For that reason I look for good results from the Norfolk & Western electrification, as described by Mr. Gibbs, and from the division of the Chicago, Milwaukee & St. Paul road now being electrified in the west. When we get the results from the operation of these roads, I think we will have figures which will be of interest to you steam railway men. I might incidentally state that the electrification of the Sarnia Tunnel of the Grand Trunk, a short engine division electrified under my direction some ten years ago, has proven not only successful from an operating standpoint, but also profitable from a financial one.

My particular function now is to endeavor to convert Mr. Lee and some of his friends to the desirability of ultimate electrification of the steam roads occupying rights-of-way in Chicago. I will admit that there is one very difficult phase of the matter, that is, what to do with our steam railroad terminals so as best to serve the city of Chicago and also the roads themselves. Of course the officials of the various roads know much better what their particular road wants than I do, but it is possible that a particular road may not know what particular features are best for Chicago as a whole. So that, as a member of the Railway Terminal Commission of this city, I am, in common with the other members, endeavoring to point out to the steam railroads the elements involved in clearing up the situation. There are acres and acres of land, within or near our business district, now used for storage of material—storing of freight cars, sand, crushed stone, etc.—which property could just as well be so commercially developed as to give a sufficient capacity for railroad purposes to last for some time in the future, and at the same time make it available for other much needed commercial purposes.

Mr. Lee has furnished good ideas in meeting the problem. In the working out of the problem Dr. Goss and the other members of his commission have in charge the matter of analyzing the smoke abatement and electrification of terminal questions. He has found, as will anybody else who analyzes the question, that if the rights-of-way of the various roads which come into the city could be unified, and their uses readjusted, so that they could be utilized to the best advantage for all roads, then the question of terminals and electrification could be handled to much better advantage, and the cost of electrification greatly reduced.

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CHICAGO'S SMOKE PROBLEM.

By Paul P. Bird, Chief Smoke Inspector, City of Chicago.

Presented November 17, 1909.

I have prepared for the society a brief and very general paper upon the subject of Chicago's smoke problem. If I had attempted to write on a subject that was not one of general interest to the people of Chicago, or to this society, I would have endeavored to have gone more into detail, and written a longer and more complete paper, but I realized that this subject was of intense interest at this particular time, and that the only thing necessary to secure a good meeting was to write a general paper, and one that would be suggestive of discussion.

At the beginning of the present city administration, Mayor Fred A. Busse appointed a committee of eight citizens to advise him about Chicago's smoke problem, and also to decide on the policies and plans to be followed by the smoke inspector in his work. The committee was called the Smoke Abatement Commission and the gentlemen appointed were:

Thos. E. Donnelley, chairman
A. C. Bartlett
E. B. Butler
John V. Farwell
Frederick A. Ingalls
William V. Kelley
Bryan Lathrop
John G. Shedd

Mr. Ingalls has since resigned but the other seven members are still active in the commission's work.

Based on the commission's recommendations, a new ordinance was drawn up and passed by the city council on July 8th, 1907. The new ordinance created the present department of smoke inspection. Before this time, the smoke inspectors employed by the city were under the department of steam boiler inspection. The head of the new department is appointed by the Mayor, but the other members of the department are under civil service. The ordinance further provided that the head of the department and his principal assistants should be mechanical engineers.

The chief way in which Chicago's new smoke ordinance differed from the old one, and in fact from any similar ordinance in existence, was that it provided that before a new steam plant is built, or any alterations are made in an old plant that may affect the matter of smoke, the drawings for the new work or alterations be submitted to the Smoke Department, the designs approved and a permit issued for the work. That part of the ordinance which defined a violation and the fines therefor, remained the same as in the old ordinance.

The present smoke inspector was appointed in September, 1907 and Robert H. Kuss, chief assistant shortly afterward. It took some time to hold civil service examinations and to get the other members of the Department together, and it was not until the spring of 1908 that the organization was complete and the work really under way. Provision was also made to furnish the Department with engineering advice by the organization of a Board of Advisory Engineers. This Board was appointed by the Smoke Abatement Commission. The engineers appointed were:

A. Bement
George M. Brill
Jos. J. Merrill

Mr. Bement has since resigned and Stephen G. Hobert was appointed in his place. The Board has met in the Smoke Inspector's offices on an average of once in two or three weeks.

During the fall and winter of 1907, the Smoke Abatement Commission, Board of Engineers, and the writer, spent much time and study in formulating the policies and plans to be followed. It was appreciated that the problem was a difficult one. This is one of the greatest manufacturing cities of the world, getting practically all of its heat and power from a local soft coal that must be burned with great care and skill in order to prevent smoke. There were about 17,000 boilers, 13,000 smoke stacks and 5,500 high pressure steam plants and the City had allowed these plants to be installed without any intelligent or careful supervision over the features that effected smoke. The science had progressed far enough that in newly designed stationary plants, it was relatively an easy matter to produce a plant that could be operated without smoke, but this was not the case in the limited space available in a railroad locomotive or in a steam vessel.

It was the idea of those who studied the problem at this time, to so map out the work for the Department, that permanent and lasting improvement would be made along sound engineering and business lines, rather than to attack any particular offenders that might be in the public eye. It was further realized that the work would be largely a campaign of education and that the results would come slowly because in a great many cases plants would have to be practically rebuilt. It was also appreciated that the City could not afford to appropriate sufficient money to support a department large enough to complete a work of this magnitude in a short time.

As a result of the study of these conditions, it was decided that the Smoke Department should not only call the attention of the owner to the fact of the smoke, and insist that it be stopped at once, but, that the Department should point out to the owner the reasons why smoke was being made and then give him sufficient time to correct the faults before suit was begun. When upon investigation it was found that a plant could be easily operated without violating the ordinance, it was decided that the Department should immediately bring suit if the smoke continued. If found impossible to operate a plant smokelessly and the owner did not at once act on the department's request that the necessary changes he made, it was decided that suit be instituted. But in general, suit should not be started when the offender was doing everything possible to stop it. The key note of the policy decided upon was co-operation between the city and the citizen.

Guided by these policies, the Department has been working for about two years. The down town district has received the most attention and in this part of Chicago probably the greatest improvement is seen. As far as the capacity of the Department would allow, work has been carried on all over the city. In manufacturing districts, on the railroads and on the river, the smoke has been considerably lessened. The Stock Yards district, for years one of the smokiest in Chicago, because of the Department's work has been greatly improved. The Railroads have co-operated splendidly with the City and undoubtedly have tried harder than any other class of smoke makers to stop their smoke. Today there are two or three railway terminals in Chicago that are probably making less smoke than any other railroads in the country using soft coal. This improvement has chiefly been brought about by discipline of firemen and engineers. The Department's greatest problem is with the river boats. The City has no control over the boiler and furnace equipment in these vessels as the Federal Government inspects such machinery. Therefore the Department's efforts have been directed toward obtaining the best operations possible with the equipment. These crafts all use Pittsburg coal. The Department has decided to change its policy in dealing with the tug boats and next season they will probably find it necessary to burn hard coal.

In general, the Department has found ready co-operation. No one apparently desires to wilfully or maliciously violate the smoke ordinance, but it has been necessary to bring suit in a great many cases, before the offender is brought to realize that the matter is a serious one. This work cannot be accomplished without a strong and relentless policy of punishment of violaters who fail to take advantage of opportunities offered them.

After two years of experience, the Department is now strengthening the policies adopted at the beginning. During this time, there has been a considerable change in public opinion, regarding the smoke problem. The chief asset that such a Department can have in any city, is a strong backing by the public, favorable to smoke abatement. This feeling on the part of the public is now very much stronger than it was in the fall of 1907. Further, as the work has gone along from month to month, the smoke offenders of the city have had opportunities to correct their plants and of learning how to operate them without making smoke. Therefore, the Department is becoming more strict day by day and is excusing less smoke and bringing more suits, and the next two years should bring about very much greater improvement.

Many citizens display very selfish motives in connection with Chicago's smoke problem. The public wants a cleaner city, with clear skies and clean buildings, but the average individual wants every one to reform except himself. A man appears never to see his own chimney smoking, but his neighbors stacks, in his mind are usually bad nuisances. Many a man who complains the loudest about a laundry or school house near his home, or about the chimney near the window of his down town office, or about the locomotives of a certain railroad, owns a factory on Goose Island or in the Stock Yards that contributes a far larger amount of smoke to Chicago's atmosphere than the stack of which he complains.

The Smoke Department is often criticised for giving engineering advice to citizens about their power plants, and it is said that in consequence, consulting engineers are deprived of work which should rightfully come to them. The Department does not want to do this and the ordinance does not require that it should do it, but conditions seem to make it necessary. The average manufacturer or owner of a power plant knows nothing of mechanical and consulting engineers and their work. He does not realize that smoke prevention is an engineering subject and that all cases are not solved by the same formula. The usual manufacturer feels that he can buy a boiler and install it precisely as he would buy a wagon or a new machine for his factory. The reason for this situation is deep-seated and cannot be discussed here. Good engineering is needed in this work. When the plans for a new plant go through the Smoke Inspector's office or in those cases where a good mechanical engineer is employed, the task is simple. No time is wasted in discussing simple details, and when the plant is put in operation, there is some one available to look after it who is responsible and capable. However, about seventy-five percent of the cases that come up are not handled in this way and the Department, in order to facilitate matters, does give a good deal of engineering advice. There is great need for engineering in small plants, but today the engineers do not seem to get the work. The Smoke Department is continually suggesting and recommending that people put their plants into the hands of competent consulting engineers, but very little work is handled in this way.

DISCUSSION.

President Allen: The smoke question that we are to discuss this evening is evolutionary in its nature. The first thing that we try to make and the first evidence of industrial progress, is the smoking chimney. When we see it on the prairie we know that business has started somewhere; when we see it on rails we know that transportation is on its way; but this is an instance of where a good thing sometimes gets to be too much of a good thing, and becomes an evil. We unfortunately get most of our light through the atmosphere. We also have to breathe the air and to look through it, and that makes it necessary for us, in the interest of public health and of civic duty and patriotism, to look after the smoke that we have taken so much pains to produce; and now, after the industrial development of Chicago has brought us so many smoking chimneys, so many steamers on the river, so many trains and engines at our many terminals, we are forced to go back and endeavor to suppress this evidence of prosperity and try to ride both horses at once—have business without smoke.

The present administration of the city has, it seems to me, taken a long step forward in the matter of scientific regulation of the smoke problem.

I have had occasion to say a number of times, and I believe it will bear saying again, that I conceive it to be one of the chief duties and best features of a society like this to bring up for discussion, public questions which have a bearing on engineering, or which are engineering in their nature. The question of smoke prevention is certainly one of these, and I am very glad indeed to see such a large attendance this evening, and to observe so much interest manifested. I think we ought to encourage the discussion of such questions in our meetings, so that engineers will be thoroughly posted on public questions, and will know how to vote when the time comes, or how to serve the public intelligently, if called upon to do so.

Mr. Thomas E. Donnelley (President, Smoke Abatement Commission): I do not think that I can say anything on the engineering side of this question which would not be very commonplace to you here, but I would like to say just a word about policy, and about the Commission itself.

When the present Mayor took office, the question of smoke prevention was brought before him by the *City Club*. The Mayor had an idea that this question of smoke was one which ought to have engineering treatment, and he thought it was a question that could not be handled by hard and fast rules. He accordingly decided that he would turn this entire matter over to a Commission of business men in whom he had confidence, and in this way take it entirely out of city politics. You know the question of smoke abatement has been bandied around from one administration to another through various smoke inspectors who were not engineers, and, whether it was true or not, there was a great deal of talk of scandal connected with the office. The Mayor appointed this Commission of eight business men, of which I happened to be one, and being the youngest they made me chairman so I would hustle; he not only asked the Smoke Inspection Department to co-operate, but he turned over the entire department to this Commission.

Now, this is different from any other department in the city. The Mayor has never given us an order since this Commission was formed. He left to us the selection of the smoke inspector, who was a man that the Mayor had never heard of, and whom we ourselves had never heard of until we began to inquire for someone who was competent to fill this office. In whatever direction we went we heard of Mr. Bird. The Mayor allowed us to redraft the ordinance to suit ourselves, and made an appropriation four times as much as had been made before. I want to make that plain, because people in Chicago are constantly getting the idea that the Smoke Department is in politics; that it is under influences which have been strong in the city for a long time. This is a fallacy, and anyone who knows anything about city politics knows the power which aldermen and other people have, and how hard it is for the head of a department to turn down a semi-reasonable request of an alderman. Now, as I said before, the Mayor has turned this matter entirely over to the Commission, has asked us but one or two favors, which were so reasonable that they were granted immediately.

The newspapers seem to have overlooked or forgotten this fact, and they constantly mix the matter up with the old political regime of he Department. Every policy that has been carried out by the Department has been settled in meetings of the Smoke Abatement Commission. We, of course, are busy business men, although I am the least busy of them all. We have had meetings on an average of once every two or three weeks, and there is no phase of this question, from engineering to all kinds of policies, that has not been brought up before these gentlemen, and, after full deliberation, settled. Of course, we are not engineers, and in order to obtain independent engineering advice when complaints were made against the policy, as they always have been, we asked for a board of consulting engineers, and I think you gentlemen know who these engineers are. When a question or plan comes up between the Department and an operating engineer, it is immediately referred to these engineers, who refer the matter back to us with a report.

I want to make these statements so it will be realized that we are trying to handle this thing in an absolutely direct way without any influences whatsoever. These Commissioners are so earnest in this matter that they decided from the very beginning that they were going to treat themselves just the same as they treated anybody else, and one of the Commissioners is now being sued for making smoke on account of carelessness in handling his plant. I mention this so you may know we are showing no favoritism. Of course, when we started in, this question of smoke prevention was like a great many other things, and most people thought it was just another one of those periodical propagandas for excitement to do away with smoke. We have been in office two years but have not accomplished as much as we thought we would when we started. I believe, however, that we have made very substantial progress, and we certainly have found out now where we stand, and we are going to push it with a great deal more vigor than we have before. Most of the gentlemen present know that the prevention of smoke, even in a stationary plant, is not a question of a fixed formula. Some plants can be operated very easily, while others are operated with great difficulty. The result of that certainly calls for the use of discretion on the part of the executive officer of the city. Theoretically that is absolutely wrong. If an executive officer of the city is enjoined to do something by law, it is up to him to do it. Of course, if an executive officer assumes this discretion it makes him liable to all kinds of inferences against his honesty. Now, the Smoke Abatement Commission has established this policy and is standing firm on the use of discretion. We are not going to sue a man if in our belief he is doing everythng he can to prevent smoke.

You know there have been quite a number of sensational articles in the *Tribune* recently, in which intimation was made that the smoke inspector had either been bribed or was derelict in his duty, because he did not sue the Illinois Central and the Chicago & Northwestern railway companies, and that he had sued two or three other plants in town very severely. We have had the very best co-operation that any of the roads could give us, on the part of the Illinois Central and the Chicago & Northwestern railway companies. When we were first organized we asked the presidents of these roads to meet us at luncheon, which they did. We told them that we wanted their co-operation. They promised to make, at their expense, any abatement that we asked; if apparatus appeared to be effective, they would install it, and would institute a severe discipline of their firemen, if necessary. Of course, some railroads have done better than others, but these two roads especially have helped us greatly. The C. & N. W. Ry. Co. has six men on the tracks all the time—smoke inspectors—who are teaching their firemen how to fire, reporting negligence and disciplining the men. The Illinois Central R. R. Co. were just as good for a while, but they have the thing down so fine now that they don't need quite as many men today. We are not going to sue the Illinois Central and the Chicago & Northwestern railways if we believe that they are doing the best they can, and are disciplining their men; but if a man who has a stationary plant thinks that by "jollying" and writing us, and putting us off he can continue making smoke at his plant, we are going to show him that he cannot do this, and will sue that man until he makes up his mind to be a good citizen.

Perhaps at times we have been quite harsh, but we are going to be a good deal harsher. We have taken the stand that two years' time was reasonable enough for any man to fix up his plant, and the rule is, if a chimney is found smoking twice in thirty days, the owner (or operator) be sued. We expect to extend that rule to the outlying districts as fast as possible. We never begin suit, however, until we have sent one of our deputies to investigate the plant and talk the matter over with the operator; if he is willing to co-operate either by better operation, or changing his apparatus, we give him time; but when a man puts himself in an opposing position, or refuses to insist upon proper discipline of his firemen, then we sue him.

I want to make this statement, because I feel there are a great many people in Chicago who do not understand the situation. The Smoke Abatement Commission, by the authority and permission of the Mayor, are running this Department, and if you have any complaint to make against the Department, or think that you cannot get satisfaction and that the Department is inefficient, kindly make your complaint to us, and we will investigate your case.

Mr. R. H. Kuss, M. W. S. E. (Assistant Smoke Inspector): Out of modesty I should play a thinking part in this discussion, but it seems that honors are thrust upon people sometimes, because of the position they hold. In line with the paper itself, it is only fair to say that the Department has found it necessary to modify and change its policy from time to time. A large portion of the changes that have taken place have come about because of a lack of sufficient knowledge, in some cases, on the part of the people in the Department, and in other cases because of lack of knowledge among the engineers and others in the city, making it almost impossible, especially at first, to obtain a satisfactory method of handling the business through outsiders. It has been a big handicap to us not to be able to refer the particular problems, that are all different, to engineers in the consulting business. It has also been a handicap to us to be unable to educate the engineers in our own Department, where changes have been necessary, in a relatively short period of time. It has taken us some time to find out just what is good engineering in smoke prevention. It is true that everyone can talk about smoke prevention, and, similar to the medical profession, it is somewhat easy to provide a remedy if you can diagnose the disease. Our trouble is that we cannot properly diagnose the disease. We cannot go into the details of the diagnosis ourselves to the degree that we can write the prescription, and the number of people that are competent to do that on the outside is very few. Fortunately their number is gradually increasing.

In regard to the policy of handling new work, we have undergone a few changes, and important ones, since the beginning of the work. Probably the most important thing that we have done is to come to a complete realization of the fact that to make any new insallation safe, there must be a responsible person between the owner of the plant and the Smoke Department. There must be someone else besides the man who pays the bill for installing the furnace and the Department that holds him responsible. Put it in another way; we have concluded that a good furnace, after its installation, very often fails and continues to fail until it receives the attention of a good engineer. The causes of those failures are various. As a corollary to this statement, a relatively poor furnace, properly followed up by an engineer, will succeed in nearly every case. The follow-up work is a most important part with any furnace. In connection with this work, some of us have come to the realization that we are not perpetually to be connected with Chicago's Smoke Department. We realize that the information of smoke prevention must be disseminated so that the work can go on, no matter what becomes of the men that happen to be in the Department. If the work may not be done as well sometimes by outsiders, as by the Department, it is better that the experience should be gained by outsiders in order to insure the perpetuation of the good work. That, I think, is a good fundamental principle to work on.

Now, the consulting engineer cannot take the position that he can design furnaces—meaning particularly the hand-fired furnaces. It would seem to me to be folly for a consulting engineer to attempt to design the details of a furnace, even to the same degree that the Smoke Department did at first. The consulting engineer, however, has a very large field of acivity in regard to the furnaces. He can determine the kind or type of furnace, adapted to a particular kind of work; he can select that furnace or one of that type, and leave the designs to a responsible apparatus company, and fix the responsibility on this company so he may be assured of competent follow-up work by them. That, I should say, is the proper way for a consulting engineer to proceed if he is not a specialist in furnace design.

To particularize a little bit on the mistakes that have been made, not only by ourselves, but by nearly everyone else, the one large fault that has appeared in every unsuccessful case has been the lack of draught. By that I do not mean necessarily the available draught at the base of the stack, but more particularly the available draught for the furnace. In nearly every case of boiler setting designs we have found that the connection between the boiler exit and the breeching connection with the chimney was faulty. We did not pay as much attention to that as we should have done, but that is one of the places where you will find more mistakes made than anywhere else. Another mistake that is quite prevalent and is bound to recur, and can be corrected only when the furnace is finished and in operation, is that of a disproportionate grate, and the mistakes are usually made in the direction of having them too large rather than too small. The significance of this remark must become apparent to you when you remember that the usual statement made in regard to smoke is that the boilers are forced. Of course the City Smoke Department is not concerned with boilers, but with furnaces. We find that a large cause for smoke, when all other conditions are well designed is the replacements which occur in connection with boilers.

If you gentlemen will remember one little point in connection with this subject, I think you will agree that the criticisms that have gone out about the Smoke Department are just a little too harsh under the circumstances. There is not one good reliable source of information in printed form. There is not today a place where you can look for and read up on the subject of combustion that will give you any clue how to handle any particular problem. Now then, if there is to be a remedy to that state of affairs, it would mean that someone must be prepared to supply that information and properly arrange it. That will take some money. If there had been anything reliable on the subject at the start, we would be a year ahead of where we are now, but we had to learn in the school of experience, just like everyone else. I say the criticism should be modified, because of the lack of information in good form.

In connection with the same point, by having good engineering information available to the ordinary engineer, there would be a way to prevent repetition of error. One engineer will make the same mistake as another engineer, and he has no way of telling that it is a mistake until after his own experience teaches him. The Smoke Department can do much by putting that information in the proper shape. So far as we can, we are collecting and arranging the information as it comes to us.

Mr. S. G. Hobert (Smoke Abatement Commission): I do not know that I can add much to the paper or discussion as it stands. You have heard the outline of the department rather fully, and the chairman of our Commission has presented the status of the Commission. Mr. Kuss' discussion of some details and methods of requirement for progress is a good one. He brought out one phase of the situation possibly, when he said that a good many of the plants which were only moderately well equipped were well taken care of in operation by good engineers, and that well designed plants have failed through faulty or careless operation. Speaking broadly, there are two important items or phases of the boiler and furnace proposition; that is, the design and the operation. As engineers, we are all interested in designing, and all helping towards designing. As operating engineers, many of us are doing our best to operate or to change the equipment which the owner has installed, and it is such work that to my mind offers large opportunities for our progress. Furthermore, the operators of the plant in the basement are usually drawn from wherever they can be drawn,—from sailors and dock rustlers, and that class of men,—so that we depend largely on the man who receives the least financial return for his work for the success of our furnace. It would seem that if concerted effort should be made to educate or uplift this class of labor, the effort would be amply repaid.

This morning I noted an editorial in the current issue of the *Engineering Record,* which brings to our attention the way they are handling this problem, to a certain extent, in Germany.

Smoke prevention is being combatted systematically in Hamburg by an association, now seven years old, called the *Verein fur Feuerungsbetrieb und Rauchbekampfung.* It is an organization of owners of power plants who recognized that it was to their pecuniary advantage, as well as the good name of their city, to obtain smokeless combustion. The association has been steadily increasing in influence, and now has 374 members, owning 1052 boilers and 148 other types of fuel-using plants. Many of these plants are not located in Hamburg, for the membership now extends from Finland to Alsace. The influence it has reached is shown by the fact that all the municipal boiler plants in Hamburg have been placed under its supervision, and the city pays it $1,250 for this service. Its regular work is to inspect and test the boiler plants belonging to its members and to instruct the attendants in their duties. Such examinations during 1908 raised the efficiency of the plants from 12 to 20%. The work is done by a chief engineer, four assistant engineers, and four instructors.

Particular stress is laid on the good results which follow intelligent stoking, and the association has succeeded in introducing quite widely the bonus method of paying stokers. Over a third of the boilers in its charge are now provided with aspirators for taking the gas samples, on which the payments to the men are based. The bonus paid is 5% of the value of the fuel saved, for all percentages of CO_2 over 8%, while the stoker is docked 2½% of the fuel lost when any hydro-carbon gases pass away unburned. The maximum bonus is fixed at 22 cents in a 12-hour shift and the maximum deduction at 17 cents.

The results of the association's work, in increasing boiler economy and diminishing smoke, are noteworthy, and fully confirm the arguments made at intervals for more than a dozen years in favor of encouraging better stoking. A manufacturer will install an excellent power plant, buy good fuel, and then entrust the use of that fuel to men of little intelligence with absolutely no incentive to do their best. The heavy fixed charges and fuel bills for such a plant offer a particularly strong argument for encouraging the men by means of such a system as that of the Hamburg association.

This shows the difference between German methods and methods in this country, and I think Chicago is close to the head, in this country, in its efforts to suppress smoke. I think that if the members of this society could individually and collectively give some particular thought to this phase of the question in the development of the efficient operation of all plants in their charge, and in charge of engineers throughout our city, they could no doubt effect greater good and greater improvement than an equal amount of energy put into the financial end of the policy.

President Allen: So far the floor has been held by representatives of the smoke inspection side of the problem. I would like to hear from some of the manufacturers,—some of the people who have perhaps made smoke in the past,—and I want to call next on Mr. W. L. Abbott,—a gentleman whom we all know, who probably has had more coal burned under his supervision than any other engineer in Chicago, and who also has been one of the leaders and pioneers in the scientific burning of coal.

Mr. W. L. Abbott, M. W. S. E.: For thirty years, more or less, to my knowledge, the city has been endeavoring to suppress smoke, and it is only within comparatively recent years that any results have been obtained that have been worthy of the effort. It is true that during the early part of the city's experience in the attempt at smoke suppression, the atmosphere of the City Hall was not suitable for the suppression of anything, but at the present time I think it will be conceded by those who are acquainted with the gentlemen who are at present managing this Department, that the Smoke Inspection Department is now receiving intelligent supervision, is being courageously conducted, and is entirely unhampered. But with all this, it is difficult at first to understand why some results which are being obtained now should not have been obtained heretofore. I attribute this principally to the fact that formerly no thought and no supervision were given to the plants as they were being installed, and no attention was paid to them until the boilers were selected; the furnace was built with or without design, and a chimney began belching forth smoke into the atmosphere. Then the Smoke Department began its prosecution of the plant owner, who was handicapped with an equipment with which it would be impossible to make steam without at the same time making smoke. Now, however, the smoke inspection department begins to suppress the smoke before the boilers are fired, before the boilers are set, possibly before the boilers are purchased, or at least before the furnace is designed. Thus no designs can go into effect until they have been passed upon by the engineers of this Department.

The effect of such a method of smoke suppression naturally cannot be noticed at first. Those chimneys which have been smoking will continue to smoke, if furnaces are so designed that the smoke cannot be prevented. It is only as new plants come in, one after another, that the diminution of smoke will be noticed, and it looks to me that the city must, as far as stationary plants are concerned, depend largely upon the general reconstruction and evolution of the stationary plants. The Department may, in its discretion, bring such pressure to bear upon coal users as will compel them to replace their existing furnaces with those of smokeless design. This I presume is being done, but it is something which cannot be done in a hurry, and is something which will have to be worked out with the boiler-users, by a very slow process. The Department, as has been mentioned by Mr. Donnelley, is allowed and assumes to itself the right to exercise a wise discretion in the enforcement of the ordinance. They might, for instance, discriminate between a plant which burns, we will say, one hundred tons of coal a day and makes some smoke, which might be objectionable, and a plant which would burn ten tons a day and makes the same amount of smoke, while the former would be making only one-tenth the amount of smoke with the same amount of coal that the smaller plant was using.

Concerning the experience which is being had in Germany in the suppression of smoke which Mr. Hobert referred to, it occurred to me that the association must be rather more for the improvement of boiler efficiency than for the suppression of smoke, from the fact that they pay firemen according to the percentage of carbon dioxide in the gas. The presence of carbon dioxide in flue gas indicates that coal is being burned with a less supply of air, and might indicate, and in some cases does indicate, that it may be burned with more smoke; also that reductions are made in proportion to the percentage of hydrocarbon gas which is found in flue gas. I have had some careful and elaborate searches made for the presence of hydro-carbon gases in flue gases, and although I was quite certain that they existed there, they were so elusive that they avoided every chemist that I put upon the job excepting one; he sent me a report which indicated that he found about four times as much hydro-carbon in the flue gas as existed in the coal itself!

President Allen: I think Mr. Abbott's point is well taken. and I have no doubt that the members of this society will read the paper that he referred to with a good deal of interest.

The name of that association would indicate that they were after smoke also.

Dr. W. F. M. Goss, M. W. S. E.: I am deeply interested in these very practical suggestions, explanations, and descriptions, and if I felt sure that I would not break the thread of this practical discussion, I would like to read a little romance, inasmuch as I have had pleasure in writing it. I present this, because it is in striking contrast with the practical considerations which have already been presented. If you regard it as emanating from academic halls, perhaps you will excuse it. Years ago the people of Chicago demanded that the atmosphere about them should be free from the taint of sewer gas, and that their water supply should be unpolluted, and they started a great movement which resulted in the present drainage canal. They have in the past demanded that the city, at night, be freed from the danger and inconvenience of dark streets, and light has been given them. These were demands which in their time were reasonable and right, and they prevailed. The question now at issue is whether the time has come when this great community may properly ask that it be freed from the nuisance of atmospheric smoke. The situation is so full of possible and actual misunderstandings that it seems to me a discussion along broad and comprehensive lines will not fail to be profitable. I propose, therefore, briefly to discuss the question as to what must be done to free the atmosphere of Chicago from smoke pollution.

Chicago can be made smokeless only by the absolute prohibition of soft coal burning under every condition which will not admit of perfect combustion. Interpreting this statement in the light of present-day possibilities, it means that soft coal must be banished from the homes of the city,—it cannot be used as a fuel for domestic heating; that small boiler plants, now so numerous in every part of the city, must in most cases be abolished; that indusrial fires, large and small,—the fire of the forge and the furnace,—must in many cases take new forms; and that railroad operation within the territory defined must undergo a great change. Before such a prohibition can become practicable, a condition must be developed which will enable all classes of people to supply their needs, not merely as effectively as they now supply them, but with such added convenience as may be permitted by the natural development of the arts during the transition period. The accomplishment of all this will involve a vast amount of capital. It need not all be supplied in a day, however, and in this respect the problem is perhaps not more difficult for the present generation than other problems in municipal upbuilding which have been met and solved by preceding generations have been for them. It is true that the interest on this invested capital, and possibly some increase in operating cost arising from a new order of things, will constitute a tax on the community, but so also have costs arising from every form of betterment by which a prairie has been converted into the present city of Chicago. Improved streets, water supply, sewers, lights, transportation facilities, and parks are all matters which have cost heavily; but so far as such improvements have been well directed and faithfully executed, no present-day citizen who lives in the enjoyment of them regrets the action of a preceding generation in providing them though he is taxed to pay for and to maintain them. It must be remembered that so long as men prosper, their homes will continue to improve, and that which people really want they will ultimately be willing to pay for. It is not unlikely that in the logical development of Chicago's plans for betterment, her next great step should be one which will clear her atmosphere.

The steps preliminary to the development of a smokeless Chicago, so far as they can be interpreted by our present knowledge of the art, involve the establishment of great public service stations at various points throughout the city, which, because of their size, may be readily equipped to burn without smoke the coal which nature has placed at our door. From each of these stations there will be sent out throughout the zone assigned, light and power in the form of electricity, heat in the form of steam or hot water, and fuel in the form of gas; all the stations together completely supplying the needs of the entire city. In the design and upbuilding of these plants with their attached distributing systems, it will be possible to so adjust the different classes of equipment to the demands which will be made upon them, as to insure high efficiency in operation. This fact, combined with the large scale upon which the operations would proceed, should make it possible to supply the needs of the consumer, small or large, either with heat, power, or fuel at costs in no case materially larger than those which must be met under present-day conditions. If, for example, under the new conditions, the small manufacturer is required to pay more for the gas fuel to sustain his fires than he now pays for coal, his lights and his power will undoubtedly cost him less, and the net increase in cost, should there be an increase, would constitute his share in the cost of maintaining a smokeless city. As a part of such a great scheme of development would come the electrification and probably also a good deal of relocation of the railroads, a matter which because of its magnitude should be developed through treatment by zones, rather than by individual roads.

Enough has been said to disclose the extent of the problem. It should be clear that its solution is not to be reached by the electrification of any one railroad. It is not, in fact, primarily a problem for the electrical engineer, though such engineers may have an important part in its solution. It is rather a business problem, a problem which will ultimately involve expenditures of greater sums of money than any municipality has ever yet expended or asked for. Can Chicago formulate the necessary plans, can she bring order out of conflicting interests, and can she safely and satisfactorily administer so vast an enterprise either as a municipal undertaking, or through the coöperation of great public corporations? These are the great questions, and satisfactory progress in the development of a smokeless city can not be made until they have been carefully studied and answered. They are questions, the working out of which belongs in a peculiar way to Chicago, for at no other point are the great soft coal fields of the Middle West tributary to so large a population. The coals of these fields are Chicago coals; she must use them, and nothing is more fitting than that she should show the world how to use them successfully and well. It is not too much to expect that a community which, in the lifetime of living men, has grown from a frontier village to be one of the world's great cities; which, through business pluck and engineering skill, has overcome peculiar difficulties in the disposal of sewage and in maintaining the purity of its water supply; and which, through the enterprise of its builders, has created the modern office building, the advent of which is so rapidly changing the aspect of cities, should demonstrate for itself and for posterity the world over, the practicability of burning the coal which nature has supplied without polluting its atmosphere.

President Allen: We wish to extend the thanks of the society to Dr. Goss. In opening the discussion I made some remarks as to the privileges and the duties of an engineering body, and I would like to add that we want to find the universities and the colleges contributing their ideas to this work, and I think the contribution of Dr. Goss is very important as dealing with the question in a large way. He sets a mark for us to aim at.

Mr. Wm. Wilbraham (of Montgomery Ward & Co.): I regret that I shall not be present Wednesday evening, on the occasion of the discussion of the smoke problem in our city. At the same time, lest my absence should be misconstrued, I desire to express my appreciation of the work in general and of the personal work of the chief smoke inspector in particular.

I have been a chief engineer in Chicago under many and various administrations, and have been in a position to observe how others have handled the smoke problem before, and how it is now being handled. While perfection has not been reached, more has been accomplished than is generally realized. This has been by hard work and by establishing a spirit of coöperation between the smoke inspector and the smoke offenders.

There have been occasions when the smoke inspector has deemed it necessary to warn me of the necessity of taking more care in firing, and through these warnings I have often been enabled to find out what was the cause of our shortcomings and have been able and glad to rectify them.

I think this is a proper course, and one that should be pursued where results are desired; hence I give him my heartiest support in his efforts to make a cleaner and better Chicago.

Prof. G. F. Gebhardt, M. W. S. E. (By letter): In connection with his educational work at the Armour Institute of Technology, the writer has had the unusual opportunity of coming in very close touch with the work of the Smoke Department, and can find nothing but the highest praise for the meritorious work done during the past two years. The policy of the Department, in vigorously prosecuting flagrant violators of the smoke ordinance, and in educating, not persecuting, the unwilling offenders, is the only practical way of attacking the problem. Criticism of the Department for offering engineers advice is ill placed and shows a selfish disposition on the part of those making the criticism. Large plants can well afford the services of a competent consulting engineer to look after the details of the furnaces and settings, but John Smith, who wishes to install a 50 HP. boiler in his laundry, is apt to find the cost of such services out of all proportion to the sum invested. It is the small plant which is usually the most obstinate offender because of faulty installation, and it is this class of plant which is most benefited by the advice given gratuitously by the smoke department.

Smokeless combustion is not as readily effected as is popularly supposed, and a smokeless chimney does not necessarily indicate an efficiently operated boiler plant. If the formation of objectionable smoke was productive of a heavy fuel loss, there would be very little need of a Smoke Department. The average power plant owner is after the almighty dollar, and if a smokeless chimney meant large returns to him, he would be the first to insist on smokeless combustion. But, unfortunately, a chimney may belch forth dense clouds of smoke and apparently be producductive of satisfactory furnace economy, and it is for this reason that the average power plant owner is lax about the prevention of objectionable smoke. Touch his pocket-book and he responds at once. Since the Smoke Department cannot touch the pocketbook of the average offender by advocating smokeless combustion as a means of effecting economy, it naturally resorts to the next most effective weapon, the law-suit.

Mr. A. Bement, M. W. S. E.: The smoke problem is one in which I have been interested for a number of years. In general, agitation against smoke and a smoky condition is based very largely upon grounds of public health, damage to merchandise, injury to clothing, and a foul atmosphere, any or all of which reasons are sufficient; but in my practice as an engineer it has been found that the economical use of fuel and a smokeless combustion go together. If we obtain the condition which ensures maximum economy, smoke will necessarily cease, for which reason I require no other justification for the following:

This feature of economy is one that is not properly appreciated. Many citizens feel, when asked by the Smoke Department to install the better class of furnace apparatus, that they are making a sacrifice to "satisfy the department," which is an erroneous view to take of the matter.

A very large portion of the smoke trouble may be eliminated by the employment of mechanically operated stokers, and a law, requiring their use in steam power plants of even very small size, is not only justifiable but desirable from the standpoint of economy. For a number of years many engineers have believed that it did not pay to install stokers in small plants, and in arriving at such conclusion they assumed that hand-fired plants would be operated in a theoretical manner, leaving out of account absolutely the fact that they are seldom or never so operated. In my experience in attempting to introduce proper methods of operation in such plants, I have many times been impressed with the desirability and advantage of stokers as a means of securing the result sought for but so difficult of attainment from hand-firing.

The necessity for a sufficient draft is something of the very greatest importance, and is a matter to which Mr. Bird continually directs attention. Chimneys, especially of smaller plants, are almost universally too low. In my opinion, a city ordinance should be enacted specifying the height of chimneys as well as requiring the use of mechanical stokers. The city, by ordinance, demands the use of plumbing fixtures embodying certain characteristics, and that they be ventilated in a prescribed manner. It is just as essential that the same consideration be given to the very important matter of chimneys and methods of burning fuel.

There has been much general talk of the desirability of a popular educational campaign for the purpose of showing people how to devise and install smokeless furnaces, by means of the publication of descriptive matter or personal advice on the part of smoke department officials and other interested bodies. It is my experience, however, that the most effective campaign of education is one which will convince the smoke offender that continued violation will result in enforcement of the city ordinance. Frequent efforts have been made to induce operatives of boiler plants to manipulate fires in a smokeless manner, and the problem has appeared very difficult of solution and sometimes well nigh hopeless, but in some of these very instances, when the smoke inspector became a serious factor, I have been interested and sometimes surprised to see that these chimneys immediately became smokeless. Thus, the result striven for by the engineer with only indifferent success, seems to be automatically secured when the fear of a fine and punishment hangs over the offender.

Within recent years there has been a disposition on the part of certain portions of the general public to expect and demand that Smoke Department officials act in the capacity of consulting engineers, offering advice and plans for furnace apparatus which could be employed as a cure for smoke evils. In cases where this demand has been complied with, the result has been unsatisfactory, because, in the opinion of the public, the Department becomes responsible, in a measure at least, for the operation and smokeless performance of the design, and the owner feels released from liability. Formerly, smoke inspectors were not engineers, they were administrative officials; but the demand on the part of the public for men with technical knowledge in such positions may be met by an endeavor to help the public in engineering matters, which would result in harm rather than good. Personally, I consider that a smoke inspector should be an engineer, but that he should employ his engineering knowledge for himself and for the business of his office and not for the service of individuals.

The matter of economical administration of a Smoke Department is an important subject. No Department official ever feels that he has a sufficient number of inspectors to observe all of the offending chimneys, and he is compelled to continually inform complainants that it is impossible for him to watch certain chimneys as they think he should. Under past and present conditions there is practically no limit to the number of inspectors required, because as soon as it is known that the inspector is not watching a chimney, it is quite liable to smoke up. The result is that chimneys must be continually watched and offenders frequently notified. Now, whether their chimney is smoking or not would be apparent if the interested party took the trouble to step outside and look at it. They, themselves, may be their own smoke inspectors if there is sufficient incentive, which would be secured by more severe punishment in the levying of heavier fines. In this connection, a new instrument devised for the purpose of making an automatic record of smoke, has been announced. It is connected to the chimney so that a sample of the gases pass through it, making a record on paper upon which hours and minutes are printed. In this way the owner or manager may each morning see a record of the previous day's performance and know at what time smoke was emitted, or may have proof that there was no smoke. If offenders knew that they would be subject to a large fine they would exercise greater care, but with fines of only $10.00 or $15.00 they can afford to take a chance. A vigorous and positive enforcement of the present, or, if necessary, a better law than we now have, would result in bringing the inspection work within the capacity of the staff of the Department. I do not, however, wish to appear as an advocate of drastic or unreasonable measures, as the opposite has been my position for a long time. I consider that people, in individual cases where circumstances justify, should have ample time to correct their conditions, but at the expiration of such period, they should be expected to cease making smoke.

There has been an enormous improvement since the time immediately preceding the Chicago World's Fair. Those who recall conditions during the years from 1880 to 1889, will remember that on a Monday morning in winter time it was so dark down town, from the pall of smoke hanging over the city, that lights in offices, stores, and factories were required until noon. Those who have in recent times observed the tremendous volumes of smoke issuing from the chimneys of the power houses of the South Chicago City Ry., at South Chicago, and the old Calumet Ry., at Burnside, may realize what Chicago once was, when every chimney tried to excel its neighbor in advertising that Chicago was, what some of our old-time friends would call, an "industrial city." At the present day we burn six or eight times as much coal as they did and produce very much less smoke. The reduction from stationary boiler plants has been brought about through improvement in apparatus and method of operation; that from steam shipping, to a loss in marine business due largely to inadequate harbor facilities. The only class of service which has shown an increase in volume of smoke is that of steam locomotives and domestic chimneys, for, as the city has grown, each have increased in the same ratio without being accompanied by proportionate improvement.

Chicago is the largest soft coal burning city in America, one of the largest in the whole world, and if smoke today were made in the old fashioned way, it would be necessary on week days to resort to our electric and gas lights, and we would require about four times as many laundries as we do now. This does not imply that we should be satisfied with things as they are, but that if so much has been accomplished the remainder of the remedy may be effected. A point has now been reached where it seems necessary to take account of the part our neighbors have in producing our smoke nuisance. The refinery of the Standard Oil Company, at Whiting, Indiana, is the largest individual offender in our locality, but this city has no jurisdiction there. The state has given the city power to legislate one mile beyond its borders on land and three miles on water, but Whiting, while it borders the limits of the city, is in another state. In the near future, owing to the rapid growth of population in the northwestern corner of Indiana, steps will be taken to enforce smoke regulations in that territory, but under present conditions we are in a defenseless position as far as that locality is concerned. Another example of this character has been met with in New York. Across the Hudson River on the Jersey side, an extremely smoky chimney gave great trouble on upper Manhattan Island. Not only was a very serious nuisance created there, but also on Long Island, the smoke crossing Manhattan and the North and East rivers. These examples illustrate the necessity for federal control of the smoke nuisance, also the desirability of a national society for the suppression of smoke.

The larger cities have their own departments, but smaller cities and towns are unfortunate in not having the incentive or ability which would enable them to institute the work. Cincinnati, Ohio, is an example, being the smokiest city in the United States, and even it might be brought to a realization of the possibilities of smoke suppression. Another example is that of San Francisco, oil being the fuel used in power plants, and there are only two smoke producers,—one a boiler plant using, in the crudest possible manner, a residue from oil gas-making process; the other, the works of the Standard Oil Company at Point Richmond. These two institutions defile the atmosphere and obscure the view for miles. There are other examples of this character in different parts of the country which indicate the possibilities before such a society.

Another phase of the problem which as yet has received but limited attention, is that of smoke made in the evening and at night.

In the work of improvement in Chicago, the efforts of two different bodies of citizens occupy a prominent place. It may be well to briefly outline the development of smoke suppression work in this city, according to my recollection.

From 1889 to 1893 Andrew Young, chief sanitary inspector of the Board of Health, in connection with other duties acted as smoke inspector. In 1891, the Society for the Prevention of Smoke was organized with the following officers: Bryan Lathrop, President; E. J. Phelps, Secretary, and C. F. White, Engineer, with an office in the top of the Monadnock Block on the north front. This society conducted its work with funds contributed by various citizens, employed its own legal talent, and prosecuted offenders in court as occasion required. This campaign developed some amusing features; for instance, Mr. Lathrop one day met the late George M. Pullman, who said, "See here, Lathrop, you are using that $500.00 I gave you to prosecute me with." Mr. Lathrop replied, "Yes, certainly, Mr. Pullman, we are; that is what I got it for." After about eighteen months, owing to lack of funds due to approaching financial depression, the society's work came to an end. Much, however, was accomplished, not only during its period of activity, but afterward. The *Chicago Tribune* also took a very active part in this campaign.

This was the period just prior to the Chicago World's Fair. There had been a great amount of new development, many large steam plants had been built, and others were in process of erection. Some of these were provided with plain grates for hand firing, and had coal been used it would have resulted in a great increase in smoke, but fuel oil was cheap at that time and in use in a large number of these plants; thus it became an active agent in smoke prevention. The citizens wished the beautiful "White

City," as the Fair was termed, to be clean, and it will be recalled that oil was the only fuel used at the Exposition.

In 1893, F. U. Adams was appointed smoke inspector of the Department of Health, which office he held until 1895, when he was succeeded by Daniel May, his term expiring in 1897. From this time on the *Chicago Record Herald* became an important factor in the campaign.

In 1897 the smoke inspector's office was merged with that of the city boiler inspector. John C. Schubert was appointed and held office until 1907, when he resigned. This brings the history up to the present administration.

During the last year of Mr. Schubert's term in office, there was a decided expression of public opinion in favor of more rigorous enforcement of the ordinance. The City Club, through a committee, of which Slason Thompson was chairman, began agitation, which was continued under the chairmanship of Thos. E. Donnelley, who succeeded Mr. Thompson. The Club then engaged Robert H. Kuss, as engineer. At about this time, Fred A. Busse, who had taken his seat as mayor of the city, appointed the following Commission, which met in his office at 2 o'clock on the afternoon of May 16th, 1907:

Edward J. Brundage,	Corporation Counsel.
John J. Hanberg,	Commissioner of Public Works.
Joseph Downey,	Building Commissioner.
Dr. W. A. Evans,	Commissioner of Health.
Victor Elting,	President of the City Club.
T. E. Donnelley,	Chairman of the City Club Committee on Smoke Suppression.
John C. Schubert,	Chief Smoke Inspector.
Frank Hamlin,	Attorney for the Civil Service Commission.
A. Bement,	Consulting Engineer.
Wm. Holabird,	Architect.
John G. Shedd,	President of Marshall Field & Co.
Robert H. Kuss,	Engineer for City Club.
Edward B. Butler,	President of Butler Bros.
F. S. Peabody,	President of Peabody Coal Co.
W. T. Delihant,	President of Standard Washed Coal Co.

At this meeting Mr. Kuss acted as secretary, and the minutes of the meeting are doubtless among the records of the City Club. After remarks by nearly all of the gentlemen present, a committee was appointed to devise some plan of action. Mr. Butler was made chairman, and, if I remember correctly, the committee was composed of three members of the Commission. This committee did not report to the Commission, for which reason no further meetings of the Commission were held.

The committee then enlarged its membership as follows:—

Thos. E. Donnelley, Chairman,
Frederick A. Ingalls, Secretary,
A. C. Bartlett, Wm. V. Kelly,
E. B. Butler, Bryan Lathrop,
J. V. Farwell, John G. Shedd,
Mayor Busse, Ex officio.

Later, it reorganized as the Chicago Smoke Abatement Commission with Mr. Donnelley as President. Plans were then formulated for the organization of a new Smoke Department, in connection with which a board of consulting engineers was decided upon. After plans were completed an ordinance was introduced in the City Council, at its meeting of July 1st, creating a department of smoke inspection, the head to be known as the smoke inspector, to be appointed by the Mayor, and who must be a mechanical engineer; also creating the position of assistant smoke inspector with the same requirements as to qualifications. It was also provided that the Mayor, at his discretion, may appoint a Smoke Abatement Commission of eight members, and that the Commission may name a board of consulting engineers, as well as make other provisions. This ordinance was passed by the Council at its meeting held July 8th, 1907.

The organization as effected, with salaries, is as follows:—

ORGANIZATION AND SALARIES OF NEW DEPARTMENT.

Smoke Inspector	$ 4,000	per annum
Assistant Smoke Inspector	3,000	“ “
Deputies—		
4 at $1,500—$6,000		
4 at $1,200—$4.800	10,800	“ “
Assistants—		
5 at $1,250—$6,250		
5 at $1,000—$5,000	11,250	“ “
5 Clerks	4,500	“ “
1 Stenographer	1,000	“ “
Total	$34,550	

The old organization which it succeeded, follows:—

ORGANIZATION AND SALARIES OF OLD DEPARTMENT.

Smoke Inspector	$ 2,400	per annum
7 Assistants	8,400	“ “
One-half time of clerk at $1,200 per annum	600	“ “
One-third time of Stenographer at $1,000 per annum	334	“ “
Total	$11,734	“ “

The smoke inspectors—Mr. Bird and assistant, Mr. Kuss—

were selected by the Commission and appointed by the Mayor. The consulting engineers were requested by the President, on behalf of the Commission, to serve as advisers to the Commission and smoke inspector when called upon. This Board, however, while acting as requested, did not organize until after my resignation, when Mr. Brill became chairman. The compensation of the engineers is $10.00 per meeting, as provided for in the ordinance.

The work under the direction of the Commission has been highly successful. There have been comparatively few suits brought to trial considering the results obtained, and the Department appears to be making more friends than enemies. Soon after Mr. Bird's appointment, he addressed the local chapter of the American Society of Heating and Ventilating Engineers, at which meeting I was present, and there appeared to be an undercurrent of feeling doubtful as to the outcome, and a fear that strict enforcement of the law would entail hardship and injury to their business. He again addressed the same organization a few days ago, on which occasion I was also present, and the feeling seemed to be quite different. The expressed sentiment in the discussion was, that through his enforcement of the law, he had helped them out of many troubles.

Mr. Bird has worked hard in his position, has devoted much time and energy to the work of smoke suppression, and I think he is entitled to the thanks of engineers and the community in general.

Before closing this already extended discussion, I would make two suggestions, one having reference to the Commission, the other concerning methods of the Department.

The advisory engineering talent, I believe, is in the wrong place; it should be in the Commission, the Board of Engineers being of limited value. It must be remembered that the head of the Department is an engineer, also his assistant, while the Commission is without engineering advice in its own organization, yet many of the problems are essentially engineering ones. I think that the personnel of the Commission should embrace at least one engineer. True, the Commission may call in the Board of Engineers and ask its opinion, but the engineers are in no position to take the initiative so necessary in matters of essentially an engineering character. Thus it would be an advantage to have an engineer on the Commission.

I believe, also, that at least one member of the Commission should be a city official. It may be remembered that the city is the largest single individual violator of the ordinance, as it operates several hundred school houses, a large number of water pumping stations, and at the time the Commission was formed, a considerable number of electric lighting plants besides other boiler installations, all of which presents a serious problem, and it should be an assistance to have the help of some member of the city administration. I have in mind the Dynamite Commission appointed by the Mayor, consisting of thirteen members, among which are six engineers and experts and six city officials.

With reference to the work of the Department, I think a classification of stationary steam plants is desirable. For example, let it be assumed that four classes be established:

No. 1 would embrace such apparatus as could be depended upon to be smokeless, independent of the care received. An example of this character is in the electric power house at Harrison Street bridge.

No. 2. Such apparatus as with reasonable care in operation would be smokeless; for illustration, such as the Murphy stoker or Hawley furnace.

Class No. 3 would embrace furnaces which require reconstruction or improvement before they are in suitable condition to be transferred to classes Nos. 1 or 2.

The final class, No. 4, to embrace those plants in such condition that the only remedy is in the abandonment thereof, or entire rebuilding; as, for example, the two beforementioned antiquated street railway power houses in the southern part of the city, now on their way to the scrap heap.

The use of such scheme of classification would tend to the more thorough establishment of the work, and would be instrumental in developing a more definite understanding and realization among plant owners.

The present law I think should be given a very thorough and competent revision and the sooner it is done the better. In fact if we could have had some years ago, supervision of the installation of new plants as we have it now, some very expensive and troublesome mistakes would have been avoided. It is therefore desirable to prevent in the largest possible measure a repetition of past experience, and to make the law as comprehensive as possible, as we may not always have the present head of the Department or the Smoke Abatement Commission.

Mr. P. M. Chamberlain: There is one phase of the problem to which sufficient attention has seldom been given, namely that in relation to economy. It is difficult to drive people to spend money unless there is some direct compensation. If they find that it is cheaper to correct their smoke evil than to pay fines, it is quite likely that they will make the attempt. If, however, they find that after spending considerable money they are still in a position to be fined for smoke violations, they are very justly in a sensitive state of mind. Unfortunately there are quacks and anti-smoke fakirs, who, capable of presenting a plausible and convincing story, can find victims. The basis for persuading the violators of the smoke ordinance should be, in the opinion of the writer, that of economy. While it may be true that a small amount of smoke is not necessarily indicative of important heat losses, in the great majority of cases the presence of excessive smoke is attended with very great losses from other causes. There are concerns and engineers in Chicago who are reliable and competent to advise fuel users so that their outlay instead of being an expense will be a good financial investment.

Regarding the Smoke Department's position in giving engineering advice, it seems to me that it would be impossible for them to have achieved the results that they have already achieved had they not done so, but it occurs to me in the light of Mr. Kuss' remarks, that in the absence of literature covering the field of smoke prevention and of proper combustion, it would be a very proper and most valuable field for the Smoke Department of Chicago to enter; that of giving the public, more particularly to the engineers as being better prepared to receive and digest it, the results of their experiments, for the Smoke Department has experimented and must continue to experiment. They have acquired information which they did not have before. If this information can be disseminated among all the intelligent engineers of Chicago, it will aid greatly in what we are working for. It seems to me entirely proper for the Smoke Department to issue bulletins covering, if not the entire science, at least an attempt at a digest of the subject of smoke abatement and fuel consumption in isolated cases, with as much of the data as possible. In this way their advice and information would reach a very large number of people and would seem to me to be productive of most excellent results.

Dr. W. A. Evans, (Commissioner of Health): The administration of the Health Department is surpassingly interested in the question of air pollution. The City of Chicago has spent more than $50,000,000 to prevent pollution of its water supply. Our interests, public and private, at the expenditure of much more than that sum, have gone through a campaign for a pure food supply, the most extensive of which was the great worldwide campaign that we had a few years ago for purer meat supplies. Pure food is of course of vital consequence, and pure water is of vital consequence, but pure air is of infinitely greater importance than either of these. I think we could not find anywhere a man who would not admit that these great expenditures for the public welfare have been well disbursed.

In 1891 our death rate from typhoid fever, the most important water pollution disease, was 175 for every 100,000 people living in the community. We feel quite certain that this year it will fall to 11, and possibly to 10. That represents quite a saving, not only in human lives but also in money, and while it is very well worth while, it is my firm conviction that a campaign along adequate lines for the purity of the air will show much greater results in the saving of human lives and infinitely greater results in the saving of money and providing for the material welfare of our people.

The burning of coal results in several products, and various products that are concerned both with the coal itself and with the burning of coal, have been mixed in public consideration with the harm or lack of harm from the burning of coal. When coal is burned, as a result of improper combustion some part of the unburned carbon is discharged into the air, and along with that there is volatilized a fairly considerable mass of volatile oils and volatile substances. There is oxide of sulphur in that coal, and the carbon is turned into two chemical compounds, carbon monoxide and carbon dioxide.

The campaign that the Department of Health is engaged in is for pure air inside the home, inside the confines of our living places, and for a pure general air supply. A pure outside air is not the most important part of the pure air campaign. The greatest part of the harm that is done by bad air is done by bad air within enclosures, especially in assembling places, but of greater consequence is the harm that is done by working in places in which there is a large amount of inorganic dust.

Whereas there is a difference in the tuberculosis rate among people who live in good homes compared with people who live in bad homes, that difference is not nearly so great as the difference between the tuberculosis rate of those who work in good places as compared with those who work in bad places. For instance, bankers have a death rate from tuberculosis of 95 per 100,000, as compared with 495 for stone masons and those who work in an atmosphere containing a large amount of inorganic dust, especially sharp-edged and sharp-pointed dust; nevertheless, of great importance is the purity of the general air supply.

Now, coal smoke has a relatively small amount of carbon monoxide, which is a most noxious poison, but at the same time it is probable, by reason of the very rapid diffusion of gases in the outside atmosphere, that this carbon monoxide rarely, if ever, reaches men in sufficient quantities or in sufficient doses to be of harm. I speak now of the unconfined air. Carbon dioxide does relatively little harm for the same general reason; that is, by reason of the rapid diffusion of this gas in the outside air, and also by reason of its very low capacity for harm.

In this country, up to the present time, our efforts at smoke suppression have been directed almost exclusively at dense smoke, which means that our campaign has been against unconsumed carbon and has not been against the gases of smoke or the volatile substances and the sulphur compounds. These are much more harmful than the suspended carbon, and we are beginning to receive complaints on that account. For instance, we will say that on Madison Street there is a building sixteen stories in height, and that immediately across the street from it is another building ten stories in height. The tenants or the owners of the tall building come to me saying that the building across the street (I mean now the operators of the lower building) are running a smoke preventive installation that does not give dense smoke, and in consequence it conforms to the existing law, but that these objectionable gases are being wafted into the windows of the tall building, making conditions thoroughly objectionable.

As Mr. Bird, year by year, gets more density or carbon out of the smoke, he will find that it will be necessary to have the smoke ordinances redrawn so that they shall comprehend some other products of combustion than carbon. It stands to reason that the method of treatment of these points must be divergently different. Our effort to prevent the lifting of unconsumed carbon must be in the direction of better consumption of the carbon, but of course that is not true of these volatile porducts, including the sulphur compounds. In London the campaign within recent years has not been against the general smoke, but against the other noxious products of coal combustion.

There has been some confusion in the public mind between the effects of smoke and the effects on the health of those who mine coal, and who work in an atmosphere with much coal dust in suspension. Generally they are brought but slightly in contact with the products of coal combustion. Coal miners are generally residents of the country, or residents of a type of country in which there is much of the open, or in which there are not usually crowded habitations. I have not yet determined, however, as to the amount or prevalence of lung disease that is to be found among the workers in coal mines. I have only this to say in that connection, that here are two questions quite apart and having relatively little to do with each other; one has but little bearing on the conclusions that are to be drawn from the other.

I have mentioned that in this city we have spent some $50,000,000 in order to reduce our death rate from typhoid fever. The number of people who died in Chicago last year from typhoid fever was 338, and the number that will probably die in Chicago from typhoid fever this year will be well under 300, as I now estimate it. This will be not only the lowest typhoid death rate that Chicago has ever had, but will also be the lowest typhoid death rate that any large city in America has ever had. With 300 deaths from typhoid fever, how does this compare with bad air diseases? Last year we had practically ten thousand deaths in Chicago from bad air diseases, or one-third of the total death rate of this city was due to the group of diseases that are attributed, in a major part, to the pollution of the air. Now, if it was worth while spending $50,000,000 of the public money to get rid of this little bit of typhoid fever, is it not much more worth while to spend some money to get rid of consumption, pneumonia, bronchitis, and influenza, that together are not only the largest source of death in our community, but that do more to make for poverty than every other influence in the community combined?

We have heard the statement made that smoky cities are cities in which there is a large tuberculosis rate. We have also heard that the mining districts are districts in which the tuberculosis rate is low. In the investigation of the accuracy of these statements, we have gone simply far enough to compare the returns as they are in from Pittsburg with the returns as they are in from Chicago, with a view of discovering if there is anything in these records to sustain those statements.

[Dr. Evans here presented a comparison based on reports of the Board of Health of Pittsburg and Chicago as to mortality from bad air diseases,—that is, tuberculosis, pneumonia, etc., which were classed together,—and the result of comparison of the summaries is as follows:

1901 mortality per 100,000,	Pittsburg	521;	Chicago	441.
1905 under the same conditions,	"	524;	"	413.
1906	"	486;	"	424.
1907	"	604;	"	528.]

From this tabulation, the figures of which are taken from the recognized authorities (the United States Census Bureau), it would seem that the deaths from impure air diseases in Pittsburg are persistently higher from year to year than in the city of Chicago. During the year 1908 they exceeded the Chicago deaths at the rate of 144 for each 100,000 of population. The excess for these bad air diseases in percentages, expressed in percentage of Pittsburg over Chicago, was 21.2%.

I do not know what the figures will show when we have made studies of the comparative maladies of mining districts and of districts in which coal is consumed in large quantities. I do not know what the figures will determine, as to the harmfulness of coal dust as distinguished from the harmfulness of coal soot, but I can say that as far as these investigations have gone, they confirm the common sense proposition that dirt in the air does not make for health; that dirt in the air does not make for the well being of human beings any more than dirt in milk, or dirt in water, or dirt anywhere else.

President Allen: We thank Dr. Evans very much indeed for his talk this evening. It is not often that we engineers have the privilege of going outside of our trade, as we have had the opportunity of doing this evening. We want to get at this smoke consuming proposition in a large way. We have tried to treat it from all sides, and I am sure that we will carry away these addresses and this most valuable information, and that they will be of help to us as engineers, as individuals, and as citizens.

Mr. Joseph Harrington, M. W. S. E.: The question that is the most important here tonight is the conclusion which I draw from the various remarks. The attack on the Smoke Department by some of the newspapers have been referred to. It seems almost obvious, after hearing the discussion this evening, that anyone who would say publicly that the way to stop smoke in the city of Chicago is to assess a lot of fines, is absolutely wrong. Nobody knows any better than I do the practical difficulties of the problem. There are absolutely no two installations which offer the same conditions; they cannot be treated alike, they must be treated on their individual merits, with the application of common sense. If the Smoke Department were compelled to fine everybody who makes smoke, the thing would fall of its own weight.

One of the rules of our office, which is rigidly adhered to is, that if anybody has a criticism to make of anything or of any person or of any method, he must be prepared to offer a solution. In other words, we do not want mere complaints, we want a constructive policy. Now, the Smoke Department in Chicago offers that to the smoke producers, and they have a policy to solve in a great measure the problems which are presented to them. The application of personal judgment is absolutely essential in that Department. In many cases a fine will not accomplish the desired result. The public must be educated. The smoke proposition is necessarily a campaign of education, and if you had occasion to investigate the great variety of conditions that Mr. Bird has presented to him, and which I personally know about, you would appreciate that nobody can stop smoke in the city of Chicago by going around like a bull in a china shop, putting fines on everybody who makes any smoke. It cannot be done in that way, and I think that it is up to the engineers of Chicago, and especially of this society,—who by their natural training have the ability to appreciate these facts,—to support the Smoke Department in some practical way. It is up to us as engineers and as understanding this proposition, to place it in the right way before everyone interested, and not to condemn the Smoke Department for not fining everybody in sight.

Mr. C. F. Heal (of Borland Bldg.): We have been told about the backing our Smoke Department has, and we all thank Mr. Bird for his paper, but our difficulties are not fully understood. For instance, I am operating a plant and hire a man as fireman. He is given full instructions as to what he is to do, but the first thing I know he neglects his fire for a minute or two, and then I get a smoke notice. We go out in the street and see our stacks smoking, and immediately go back to the fireman, but that does not prevent our being called to account. I must say, however, that when I have been before Mr. Bird I have been treated very fairly, and will endorse what has been said about his use of discretion.

Mr. Alfred Johnson (Mandel Brothers): The time is short but I do want to say that if the program we have heard is being followed, and the Department is given the authority that it should have, and it uses discretion, it will continue to have the solid support of the operating engineers. I do not believe there is a body of men in Chicago who have been as loyal in their support of the Smoke Department as the operating engineers, and I do not believe there is a body of men who have spent the amount of time and energy and study of means to prevent smoke in the city of Chicago that the operating men have. A discussion of this kind brings us together and does much good, and we ought to have more of it. We also should have some scientific discussion on the elimination of smoke.

I am one of those who have been censured for creating smoke, and I do not feel at all ill-willed towards Mr. Bird. He has done everything possible to aid us, has consulted with us, has had his men in our plant, and we have done everything we could. We have spent a great deal of money and are willing to spend more, but we do not want to spend it unwisely. If something could be developed so that by spending $50,000 we could eliminate the smoke, we would not hesitate to make that expenditure, but we do want, and insist on having a perfect understanding and a harmonious feeling between the Smoke Department and ourselves. I am glad to hear what Mr. Donnelley had to say, and to know that discretion will be used.

Discussion.

Adjourned Meeting, Nov. 26, 1909.

President Allen: A week ago last Wednesday we listened to a paper from Mr. Bird on Chicago's Smoke Problem. The discussion was very full, and we found that we did not have time enough to listen to all the gentlemen who were prepared to speak. It appeared that the smoke problem was an extremely live one, and in order to cover the ground satisfactorily, to hear from those whom we wanted to hear from, and to learn all we could about it, we decided to call an adjourned meeting. I am glad to see that our expectations have been realized, in the large attendance this evening. Inasmuch as we had such a hard time getting through at the last meeting, we will start right in, and I want to call upon Mr. Bird to open the discussion.

Mr. Bird: I believe that I am not expected to talk much tonight, but to give all the time possible for others. Of course it is very gratifying to me to see such a large attendance tonight, but I know that the interest is in the general subject of smoke prevention, rather than in the particular subject matter that was in the paper that I read last week. I hope that the discussion may be very general and frank, and I am quite sure that if, at the end of the evening, we are not all talked out, the society will be good enough to let us have even a third meeting.

President Allen: I would like to state, before beginning the further discussion, that Mr. Bird and Mr. Kuss are here to answer any questions that may be asked, and in order to save interruption, I will ask them to make note, so far as is possible, of such questions, and answer them at the end of the meeting, at which time an opportunity for so doing will be presented.

The operating engineers had very little chance at the last meeting. The meeting was taken charge of almost entirely by the smoke prevention people—not the people that make smoke—and so this evening we want to give the operating engineers the very fullest opportunity. I will first call on Mr. Naylor.

Mr. C. W. Naylor, M. W. S. E. (of Marshall Field & Co.): I will state, for the benefit of my many friends and acquaintances here, that being a member of the society and not knowing after the last meeting that there was to be an adjourned meeting, I sent in my discussion, as is the custom with members of the society, expecting it to go into the proceedings. In view of the fact that there are so many here tonight who are prepared to talk, I will not address you at random; I will not even enlarge on my own views, but will simply read them to you and leave the discussion for those who came here for that purpose.

The rules regarding supervision claimed to be new by this department are not new but have been borrowed from the department's predecessor.

Intelligent supervision of installations did not originate with the present bureau. The majority of all non-smoke plants now in Chicago were installed long before the present bureau was appointed,—in most cases without any help from the smoke department.

The present department admits having made some mistakes. They say confession is good for the soul. This department, like all preceding ones, had to learn how to prevent smoke before undertaking its suppression, and it has probably accomplished more than any previous department. The statement that "Next year we are going to do things to the tugboats," has been heard before. It is a perennial and hoary chestnut with the smoke department. It has been a regular November and December stunt of all preceding smoke boards, and yet each spring we will find the same old smoke belching from the stacks of most river craft.

Mr. Bird's anxiety for the consulting engineers and their cry for bread and butter was very pathetic, but misplaced. There are remarkably few consulting engineers in Chicago who know even the rudiments of smoke burning.

The Milwaukee smoke inspector who could not see smoke on his trip about Chicago, was not on to his job. He can be shown smoke pouring from at least twenty-five schoolhouse and waterworks chimneys during a two hour ride on our elevated railroad system on any cold morning. All these schools are under direct control of a city which is trying to make its citizens stop smoking with their private chimneys.

The Smoke Department must devise some method of notifying offenders *at the time* they are violating the city ordinance, and not twenty-four hours later by mail.

The department must compel the installation of an automatic smoke recording device, either as a temporary installation for the purpose of instruction, or better, as a permanent improvement.

The elimination of color from smoke—in other words, the prohibition of *black* smoke—will not cure the worst evils of smoke, although it may increase our daylight. Large center chimneys on each block, at least 400 feet in height, will diffuse the gaseous poisons above the heads of the air-breathing public.

The Smoke Department, to be a respected and honest organization, must stop smoke from all city chimneys, whether in schoolhouses, office buildings, city halls, waterworks, fire engines, machine shops, or electric light plants, before it presumes to tell the citizen not to smoke. Plant owners should not be fined, on the unsupported evidence of one inspector, but better proof should be required to make a case.

Mr. A. L. Hadin (of the South Side Elevated Railway): I do not know why I should be the second man called on, as speaking is not my custom. I believe, however, in regard to the Smoke Department and the smoky chimneys of the city of Chicago, that there are smoky chimneys and there are not smoky chimneys, and those that are not smoky have been made so largely through the aid of the Smoke Department, as well as by those in charge of the plant. The consulting engineers, in my opinion, have very little to do with preventing smoke. They sit in an office and, like a good many doctors, have a shingle out and look wise, but it remains for the fellow who handles the fire to prevent the chimney from issuing a volume of smoke. The statement was made at the last meeting that plants can be equipped to prevent smoke under certain conditions, but those conditions probably do not exist in 90% of the plants throughout the city for fifteen minutes at any one time.

Now, who can build a furnace that will prevent smoke under all conditions? The only way smoke can be prevented is by carefully watching the handling of the plant and the furnace. It seems to me that in all this talk about smoky chimneys, sufficient thought is not being given to the unfortunate fellows who have to stay down in basements, which, in a good many cases, are not fit to stay in, but for which some consulting engineer has designed a boiler plant. Neither Dr. Evans nor the consulting engineer has made any provision for these men, and they are the ones who are going to get the blame for every dirty cinder and all the smoke. I believe that a furnace can be built and installed that will not make smoke under certain conditions, but that those conditions are rare.

In a majority of the plants where there is only one boiler, something may happen to that plant,—an arch may fall down or a tube may break; in fact, there are one hundred and one things that occur in a boiler room that cannot be prevented. Now, an inspector from the Smoke Department may see a chimney smoking, caused by such conditions, and will report the matter; then a notice from the Smoke Department will be sent. I believe that some concession should be made in such cases, and that violators should be notified at the time the smoking occurs, so that those who are making the smoke may see for themselves.

Mr. J. H. Morrow (of the Great Northern Hotel): I was present at the meeting last week and, like many others, realize the opportunity that has presented itself to our City Smoke Department to follow this question in a more vigorous way than they have in the past. Mr. Donnelley, the President of the Smoke Commission, outlined the policies that they intend to follow in the future. I fully appreciate the position in which the Mayor was placed when he appointed this Commission. I believe it was a fortunate thing for the Mayor, because it shifted the responsibility to other parties, and more particularly to business men who have to cope with this proposition. At the same time I realize, and I think my fellow engineers will agree with me when I say that the conditions that exist in boiler rooms are not altogether ideal.

The operators of furnaces have been endeavoring to co-operate with the Smoke Department to prevent the nuisance that our Health Commissioner, Dr. Evans, claims is so injurious to the general public, and I think the engineers of this city have given their co-operation, almost to a man, to prevent it. Mr. Bird, the chief smoke inspector, I think, realizes that the engineers are endeavoring to work with him.

We have a great many kinds of coal to contend with, and we all know that when our plant is designed to perform a certain duty, whether the boiler is underloaded or overloaded, there is a point in every boiler plant that is economical. For instance, when we start up a cold boiler we are going to make smoke, because we must obtain temperature before we can consume the carbon and prevent the making of smoke. Also, if we overload our boiler plant we are going to make smoke. Now, those are the conditions with which the operating engineers of this city are confronted, and I do not believe that these conditions are entirely taken into account by our present Smoke Department. If some kind of a system of notifying the operating men could be devised at the time the plants were smoking, I think that we could work together in a manner more nearly harmonious.

I think that at the time the Commission was appointed to co-operate with the Smoke Department, that a Commission should have been appointed to sample the coals that come into this market, and that are delivered to buildings after they come into this market. It is a fact that where you expect to get certain grades of coal, in certain instances you get a bad load of coal, or a number of them in your plant, and you are going to make smoke. The plant must be kept going at any cost; that is the first requisite of any good engineer. So the Smoke Department and the business men of this city should realize, if they have not already done so, that the coal market of Chicago should be taken into account, in the plans for prevention of smoke. If we can get a high grade of coal—one that comes up to the standard—and the coal companies are not allowed to send coal that is under grade into our boiler rooms, this will go a long way towards the solution of the problem and will greatly assist the engineers in co-operating with the Smoke Department. We would not be here tonight if it were not for the fact that we want to co-operate with that Deparment and prevent smoke to the utmost of our ability.

Mr. Alfred Johnson (of Mandel Brothers): This subject is one in which we are vitally interested. There are without doubt many smoky chimneys in Chicago, but there are not nearly so many as there used to be. I believe that fully 90% of the smoke in the downtown district has been eliminated within the last two or three years. It used to be a rare thing to look up and not see many smoky chimneys. Now, you can go along the street and look up, and while you find some smoky chimneys, still you do not find them to the extent that you did formerly.

Smoke prevention is a hard problem. There are times when we will make smoke, when we are doing our utmost to stop it. The matter has bothered us a great deal. I have at times gone out on the street or up on the roof of our building and found our chimney smoking. I would then telephone to the engineer and ask him what he was doing. He would make an examination and reply that everything was as usual, and he could see nothing wrong. I have then gone downstairs immediately, and in looking through the boiler room have found that he was apparently telling the truth. Possibly a little closer inspection would have revealed a hole in the fire somewhere, but that is hard to see.

There are other times when we know we are making smoke and that we shall have to continue doing so for some little time. We had a case a week ago when a flue blew out and a lot of water drenched the fire. I knew we were making smoke, but fortunately for us the Smoke Department did not discover it. The water put the fire out so fast, however, that probably the smoke did not last for six minutes. It happened to be a bright day, and we were able to get along with the rest of the boilers without serious inconvenience until we got another one ready. If it had been a dark day when we would have had to carry a maximum load, I know we would have had to smoke for over an hour.

It is with things of this kind that I want the Smoke Department to be given the power of discretion to forget and forgive. I think they ought to be endowed with that power, and I believe Mr. Donnelley intimated as much. I thoroughly believe it is unfair to be fined for something one cannot prevent, when he did his best to do so.

Another thing I fully believe in, is that the Smoke Department should more than ever co-operate and advise with the engineer and I do not think that the Department ought to be curtailed. It has offered advice freely, and has done much to help the engineers, and I think this service should be extended instead of being cut off. If the Department has not the proper amount of help, it should ask for a larger appropriation and have more prominent and practical engineers to advise with the operating engineers.

I do not think there is any need of advocating, or in fact, asking the consulting engineers to go into the work, because I have not found any of them who knew any more about it than the operating engineers. They may tell you to try this and try that and maybe you will succeed, and maybe not.

There is no absolute cure for any smoke problem. Each individual case must be considered by itself. The Department at present sends one inspector who advises; this is a good practice, but I think two men should be sent to go over the matter thoroughly, be sure of their ground, and then advise. If the advice is followed without success then the engineer should be exempt from censure until something else is tried.

It has been very discouraging to many of the engineers who have been able to run their plants for a time practically without smoke, to have failures occasionally. The average plant down town is fairly smokeless, and I do not think any of them that are well equipped and taken care of smoke one-eighth of the time as the law allows. Anyone may smoke six minutes in every hour, but if he makes no smoke for a whole day, and then the next day smokes six and a half minutes in one hour, lo and behold he gets the axe. It does not hurt the operators' feelings nearly so much as it does those of the owner of the plant. The engineers become case-hardened, and say: "Well, we did the best we could; of course, if smoke escaped, we regret it, but must grin and bear it." We all know, however, that if we continue to make smoke our employers get very much wrought up about it. It is not so much the fine that they have to pay,—

because they have spent probably ten times that amount, or a hundred times as much, trying to put in a device that would prevent the smoke,—but it is the fact that they are brought up in court and sued that hurts them.

I think the ordinance ought to be changed so as to allow the Smoke Department to use discretion, in case it finds that the plant is being operated to the best advantage under existing conditions. Where the owner is willing to do anything and everything that the science of smoke prevention has decided should be done, he ought to be given the same privilege as the railroads are given.

Mr. John F. McGrath (of the Hartford Building): I came here, although I am an old fellow, on the theory that it is never too late to learn. I did not come to talk. I will say, however, that when an old friend is about to pass away, a man is indeed an ingrate if he has not a good word to say for him, and consequently I say that smoke is Chicago's best friend.

The tale of suppression of smoke in Chicago really began with the tail of a shirt. I was in the Council Chamber something over 36 years ago, on the 10th of November, 1873, when a petition was presented asking the Council to compel the North Chicago Rolling Mill to burn its smoke. That petition was signed mostly by residents in the neighborhood of Union Park, which was the first pretentious park that was finished in Chicago, and at that time they thought it was going to be the principal residence district of the West Side. To show that it was not brought in under any particular proposition, it was referred to the committee on fire and water. The claim made was that when the wash was hung out on the clothes-line (and in those days we never dreamed of such a thing as the steam laundry jumping up to be a thorn in the side of the Chicago Smoke Department) the smoke from the Rolling Mill, three miles away, got to the shirt before the sun did, consequently they could not vie in the purity of their linen with their brothers of the South Side.

The Mill at that time was a very large institution, probably the largest industry in Chicago, working 24 hours a day, making iron rails, and it sent up a pall of very thick smoke for about two or three miles around. Now, I might not be able to argue with my learned friend, Dr. Evans, who spoke here for the Board of Health, but I will take the lawyer's argument and prove an alibi. That Mill at the time had between two and three thousand of the most robust, healthy men I had ever seen. They made plenty of money, worked plenty, ate plenty, and I would be the last to claim they did not drink plenty. The agitation caused a good deal of discussion and argument, as well as some little annoyance to the parties interested, and it was claimed that such a thing as burning the smoke was out of the question. If they had shut down that plant it might have resulted in shutting down Chicago, so they simply wound up by consigning the signers of that petition to the place where all authorities agree there is a great deal of fire, and where I think theological history would say there is some smoke. This kept on for a couple of years. There was not much done, but two or three years afterwards, at every meeting of the Council there was a mass of from ten to a dozen petitions from men and firms, asking permission and guaranteeing absolutely to do away with the smoke nuisance at a percentage of saving—well, you might write in your own percentage, they left it blank. And so the agitation was kept up, through the newspapers and otherwise. I remember that a committee was formed, and after they had gone out and made a public inspection of Bill Jones' patent smoke burner, they described the great invention and showed where Jones had discovered that steam at a temperature of 327 degrees would consume all smoke, adding that any engineer and fireman who continued to make smoke after that demonstration ought to be in jail.

I will never forget one day meeting the late lamented Joseph Medill, chief editor of the *Tribune;* he had been down looking at a demonstration of Smith's patent burner. (There were seven Smiths here at the time, and this one was a man they called Crazy Smith.) He began explaining to me the amount of money Chicago property owners would save in the first cost on a practical smoke consumer of that kind. The smoke-stack would be done away with altogether, and all that was needed was a little piece of pipe. It was a "simple" invention; a large steam jet in the breeching of the boiler forced the gas under the fire, so it went like a merry-go-round, from one to the other. Very few of us tried it; so we kept on until after the smoke ordinance had been passed, and then the operating engineers were up against the proposition; smoke had to be done away with, and they commenced to get busy.

Along in the 80's, nearly every second or third man running a plant had a patent smoke burner. We cut down capacity, and we finally did away with a great deal of the black smoke. Along in the early 90's there was a great wave of reform, a Commission was appointed, well-meaning men put in their money, and the city was going to do away with smoke once and for all. That was the first time in the history of Chicago that we could have gotten a practical method of doing away with smoke, yet that Commission I claim was the biggest fizzle we ever had and set back the suppression of smoke for many years. The first move they made was to hire a lawyer. Then they met and mixed up a prescription and sent it around to all the operating engineers. I think it was to be taken three times a day, before firing, and, like the small-pox, if it did not "take" in ten days, the lawyer got the case. Well, it only took in about one-half of one per cent of the cases, and the lawyer was kept so busy that he ate up all the funds, and then the whole thing went up in smoke.

About that time the skyscraper was inaugurated. The people of Chicago had gotten to a period where they could do things which they could not have done when the subject was first brought up. Thirty years ago it could not have been done, and if an attempt had been made there would have been nothing here today of which to make a city beautiful; but at this later time I claim it could have been done, and, through a practical rule and practical supervision, an immense amount of good could have been accomplished.

So we kept along until a few years ago when the next Smoke Commission was appointed, and now we have supervision of the installation of the new plants. The younger men may say, "Well, you old fellows did not know anything." I contend that this is not the case. An architect designs a building, and it is left for the operating engineer to solve the problem of how to burn the smoke. Now, at least, if the plans are not properly made, the Department sees that you have room in which to work out your salvation. In that respect I claim the present Smoke Department is the best we have ever had, and it is on the right road to success.

As to the workings of the present ordinance, I must say that the Smoke Department has done a good deal of good in the way its representatives have gone around among the plants giving advice in regard to the installation of new plants and the reorganization of old ones. Of course, they have brought suits, and I would not like to be guilty of a breach of courtesy to this Society and use the language I would like to in regard to some of the inspectors, because, like many others, I have had my day in court. I have paid the bills, however, and it is seldom that a man is brought in under the smoke ordinance that he is not proven guilty,—at least practically guilty. He might have lots of extenuating circumstances, but he could not prove an alibi.

The only time I was ever sorry for pleading guilty was years ago before a Justice of the Peace. The case had been postponed several times, and when finally called for trial I said, "Why, yes, I am guilty." The judge wanted to know how bad I was guilty, and asked the inspector to read the charge, but the inspector had forgotten his book. The judge then said: "The best thing you can do is to go and pay the costs and go home and behave yourself."

The first man I ever worked for when I came to Chicago was Gurdon S. Hubbard, and I have often heard him tell the story of how he once paid the entire taxes of this city. That was years ago when this part of the state was in Vermillion County, with the county seat in Danville. He said there were a couple of small tribes of Indians that got very playful and frisky around here, and sooner than come up from Danville, he put his hand in his pocket and paid the entire tax of the city of Chicago, which was $2.30. And this man's widow is right here in our midst today, a good, healthy woman yet. Is there any other city in the world where a woman can get up and say: "Well, my husband paid the entire tax of that city, only about half a day's pay." Then think of our millions of people and our hundreds of millions of dollars invested! Mrs. Hubbard does not attend the meetings of the Ladies' Auxiliary, neither does my old friend, Mrs. Clybourn. They both came here a long time ago, and say that when they got here the only way they knew that this was a city was because they could see smoke. The only thing that gave Mrs. Clybourn any encouragement at all was a little bit of smoke that went up. That was the only beauty about the town when she got here, and she does not attend any anti-smoke meetings. She says that smoke built the town and she doesn't see why there should be any objection to it. She is still here, hale and hearty.

You must consider that this is a wonderful city. You younger men do not realize how quickly it has grown up, and when you think of all that has been done in the suppression of smoke in the last two decades, isn't it really a libel on the young men to say they cannot find a way out of the difficulty? I think it is nonsense. They will accomplish results, and they will do so without causing the big corporations any great hardships. It has been done with the stationary plants, and surely the generation which is coming can solve this problem, which does not present nearly the same difficulty it did to us.

Now, gentlemen, when you see a little smoke coming out of a chimney where a man has just put a fire under his boiler, don't ring up the Smoke Department. It will not last long, and it will not kill you. Something more than two weeks ago I was up on the roof of my building one morning about eleven o'clock, with a friend; the wind was blowing from the northeast, and the horizon was as clear as crystal. Without fear of contradiction I will say, that from Twelfth Street on the south to Grosse Point on the north, taking in all the old North Side section, there was not one violation of the smoke ordinance.

Now, gentlemen, when you consider the hundreds of thousands of tons of Illinois coal that is burned without smoke, I think that the men who do it ought to have your support, and when the men who are responsible for the dirt and filth and ragged condition of our streets have done as much for improvement in that direction as the engineers have done in theirs, it will be time for us to compare notes.

President Allen: It is extremely interesting for us to hear of the smoke problem in a chronological way, as Mr. McGrath has brought it out, and to know the panaceas that were offered and the way that they have followed each other into the dust heap. That is the same story over again, that it is not so bad to be ignorant as it is to "know so much that aint so." We all know of so many things that have been proposed as absolute remedies for smoke, but they haven't always "proved up."

Mr. Frank Elliott (of the Northwestern Elevated R. R.): I thought until about a month ago that I had done a good deal towards preventing smoke on my side of the town, but I had my wings trimmed by the Smoke Department. At first I offered various excuses which I thought were very good, but they were not accepted, and I found that the only thing to do was to stop making smoke, regardless of expense.

If one of our men got sick, and we did not have a man to put in his place at the fires, we were told that we must keep men on the ground who could take care of the fires, and I decided that I was going to keep men enough on hand to do the work as long as I was permitted to do this. So I went ahead and tried to do what I could. I think we have accomplished much, but I know that we make some smoke.

I have seen a great deal of smoke in Chicago, but this has been very much modified in the last ten years. I have made more smoke this summer, I will admit, than I made in the previous nine years, but I am doing a good deal more work, and the times are so good that the men leave and I have to hire a few new men to keep things running, but I cannot always keep the same set.

With plenty of draught, I think any good type of furnace, carefully handled, will practically eliminate smoke. But I think that there should be a little immunity extended to men who do not make smoke more than half an hour out of the twenty-four. I believe there is a reasonable excuse for some men making smoke occasionally.

Mr. A. J. Saxe, M. W. S. E. (of the Corn Exchange National Bank): I can myself remember some of the days Mr. McGrath describes; they are very interesting; but what we wish to know is how to suppress smoke.

Last week Prof. Goss recommended that we pool all our plants into one big plant, and furnish power from one point. There could not be enough of these large plants to run Chicago anyway, as there will always be more or less small plants, and they will have to be properly taken care of to do proper work.

I remember one day in 1879, when my brother and I were walking down Adams Street, that as we passed a building where the Marquette Building now stands, there was a big brass plate on the front which said: "Hutchinson's smoke burner for locomotives and stationary boilers." I said to my brother: "What is that?" and he replied that it was a method of burning smoke. As I never had heard of such a thing, we investigated and found that it was a casting which went in the furnace and blew steam over the fire.

There is one thing in our present ordinance that I do not think is right, and I think it should be changed. That is the six minute allowance for smoke. There are some people who make four and a half, five, and five and a half minutes of smoke every hour. We never go out but we see their stacks smoking. They make smoke on an average of one hour out of twelve every day, and they never get a notice, neither are they fined. I am on the road to a lawsuit myself. We think we have a pretty good chimney. We generally fire up our green boilers at night, but on the 3rd of October, when I came down in the morning, we found a leaky tube cap and had to shut down, draw the water and take out the fire. I told the engineer to let the boiler go until night before he fired it up, but this occurred on a cloudy afternoon; the load got heavy, and he had to start it up, and in firing he made eight or ten minutes of smoke, and we got a notice from the Department. Of course, that was no more than right, we had violated the ordinance and were entitled to the

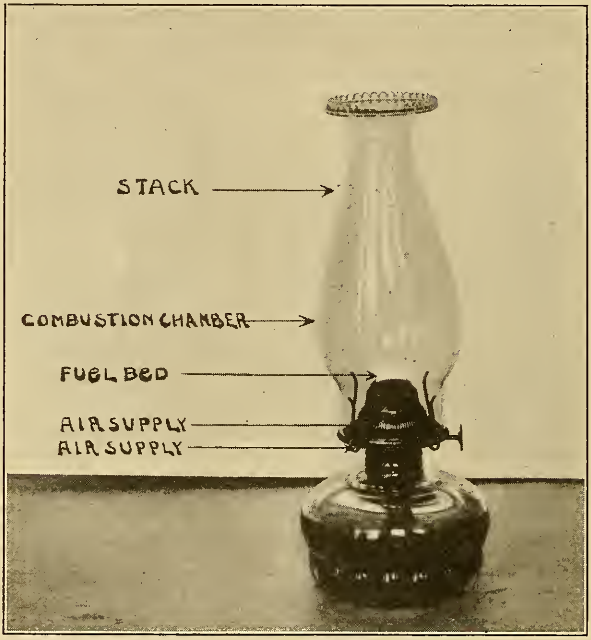


Fig. 1.—Kerosene Lamp to Illustrate Furnace Performance.

notice. From that day we did not make any smoke until the 23rd. On that day we were putting in new catches on the stokers, and in changing over from one to the other there was about half an hour when the men shut the stokers down and fired by hand. During that time they made smoke from eight to ten minutes, and we got another notice, and this time we were notified that we were sued. Now, we made twenty minutes smoke, I guess, in four months. The other plants make an hour's smoke every day and yet do not violate the ordinance. I think the man who makes the most smoke in a week or a month should be sued, and not the man who makes ten minutes smoke once in two or three months.

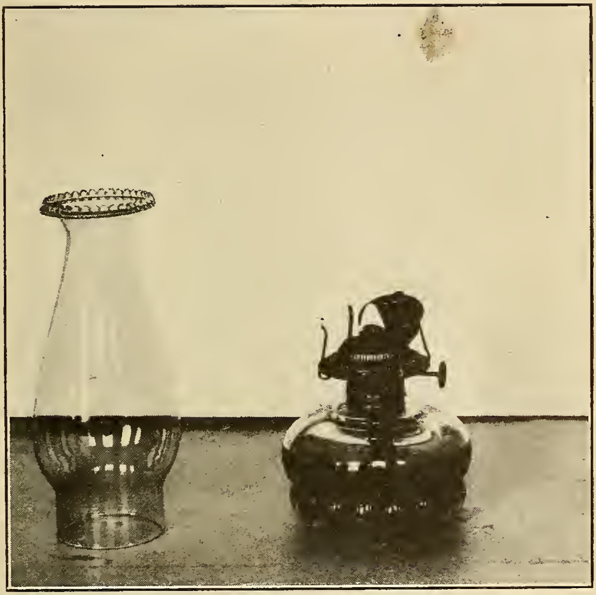


Fig. 2.—Lamp Burning with Clear Flame and Open Hood.

To illustrate my remarks, I will make a few experiments, using an ordinary kerosene lamp, the best example of a theoretical furnace that can be bought in the open market today. It is probable that the different oil companies have spent more money in perfecting the kerosene lamp than has been spent by all the furnace companies combined in furnace improvement. The result is an almost perfect device. On inspecting the lamp, we find that it embodies the principles required in a well designed furnace for burning coal; the only bad feature is that its air supply is cold. More economical results would be obtained if the air was hot, but in a lamp this is almost an impossibility.

By taking off the chimney and opening up the hood, we find that the wick can be raised or lowered to increase and decrease the amount of light required. This feature corresponds to the conditions of fuel in the furnace or the coal on the grate. The perforations around the wick and underneath the hood represent the openings in the grate of an ordinary furnace. The holes around the outside of the hood, which are inside of the chimney, are to let the proper amount of air over the flame or fire, the same as is required in a well designed furnace. The bulge in the lamp chimney represents the combustion chamber, and the chimney above this bulge represents the furnace stack. The height and area of this stack has a great influence on the strength of draft. The duty of the chimney stack is to supply

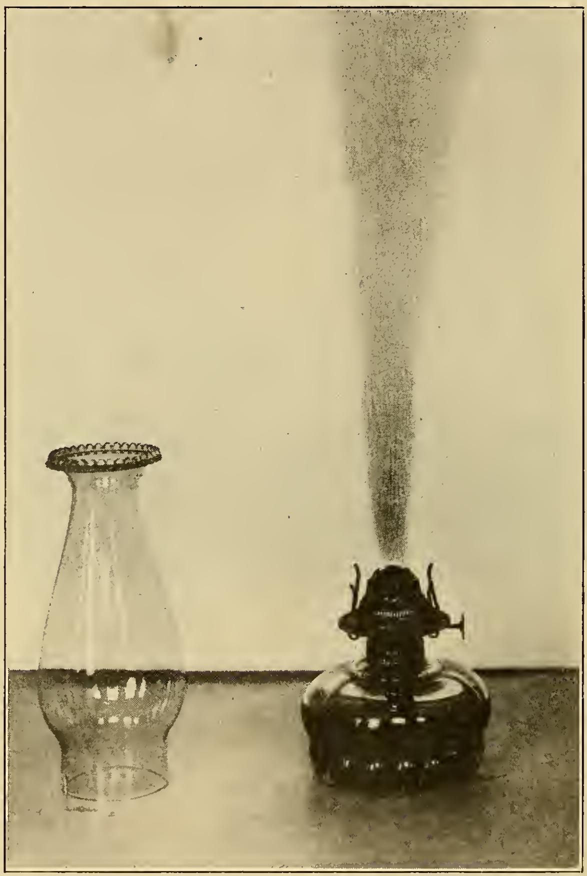


Fig. 3.—Lamp with Closed Hood and Without Chimney, Producing Smoke.

air to the furnace and discharge the hot gases to the atmosphere.

Air is composed of 21% oxygen and 79% nitrogen, but the oxygen is the only part which causes combustion; nitrogen is taken into the furnace only to be heated at the expense of the fuel, and it passes up the chimney and produces no result except to assist the draft. It is necessary, however, to pass this amount of inert gas through the furnace to get the proper amount of oxygen, the same as it is necessary to put an amount of earth matter into the furnace with the combustible. It requires 13.6 cubic feet of air to weigh one pound, and theoretically it takes about twelve pounds of air to burn one pound of coal. In best actual practice, from 18 to 20 pounds of air is used per pound of coal. If we consider how much air is required to burn a ton of coal, one may be surprised. 13.6 times 20 equals 272 cubic feet of air per pound. This multiplied by 2000 (the number of pounds in a ton), gives 544,000 cubic feet of air required to burn one

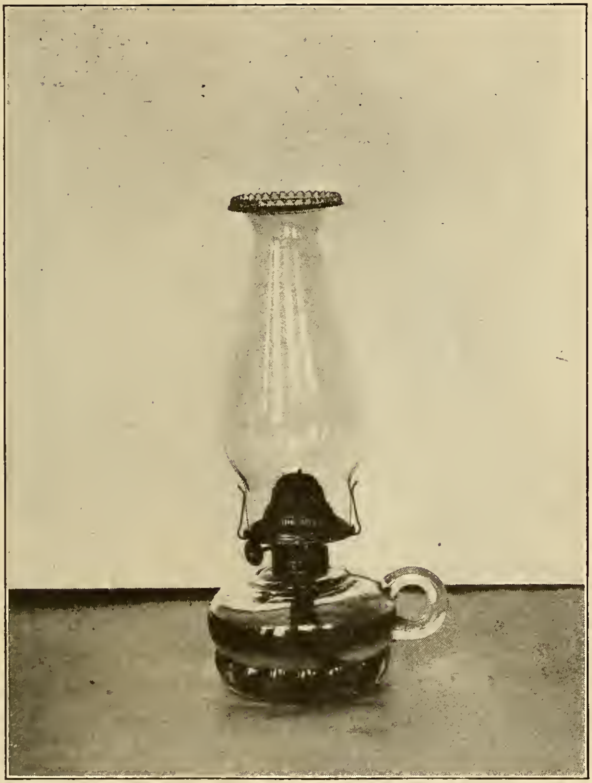


Fig. 4.—Same Size of Flame as in Two Preceding Views, with Chimney on Lamp.

ton of coal. This is more air than is contained in any of our fire rooms, and the question is, where is this large amount of air coming from? If provision is not made for it to enter the boiler room, satisfactory results can not be obtained. I will illustrate later with the kerosene lamp some of these conditions.

By removing the chimney, opening the hood, and lighting the wick, the resulting flame appears like that of a torch burning red at a very low temperature and it smokes badly. This smoke I will reduce by turning down the wick so that the fuel supply balances the amount of air surrounding the flame. We now close the hood and the flame again begins to smoke. This shows that the hood cuts off the mass of air surrounding the flame. This is analogous to a furnace running with a very poor draft; with such condition the fuel supply on the grate is usually too large for the amount of air admitted to the furnace, so that proper combustion is not secured. We now place the chimney of the lamp in position over the burner with the result that the smoke at once ceases; the flame brightens up and the temperature increases, showing better combustion and more economical consumption of fuel.

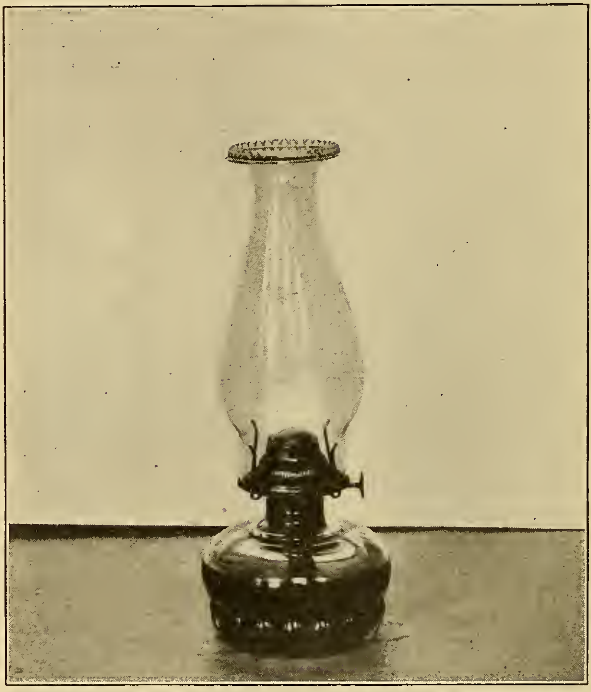


Fig. 5.—Large Clear Flame, Due to Draft Produced by Chimney.

If the furnace is a hard-fired one, with a poor draft, the fireman should manipulate it as follows: Open the fire door on one side only; place about two shovels of coal on the grate; close the door; wait for an interval of two or three minutes; then open the door on the other side of the furnace and put two or three shovels of coal on that side. This method will keep one side of the furnace burning hot and thus consume the gases on the other side, which the fresh coal is throwing off.

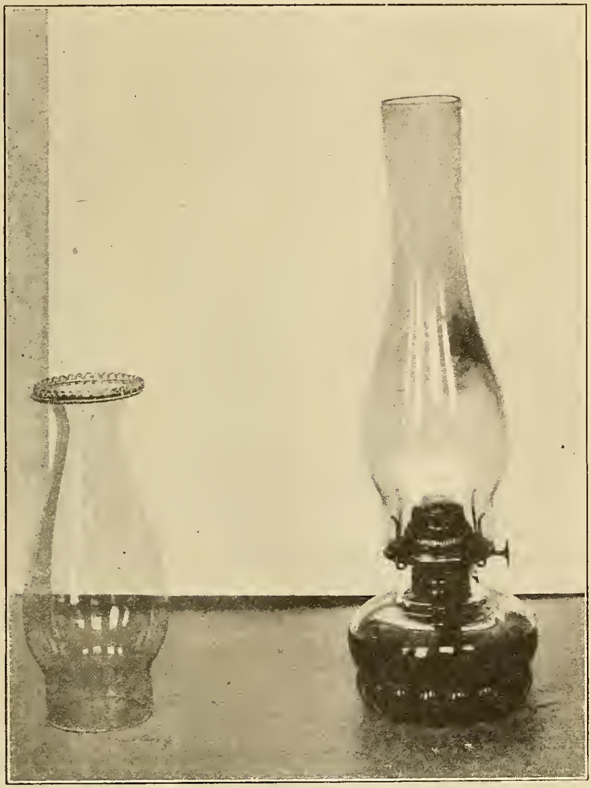


Fig. 6.—Still Larger Clear Flame, Due to Draft from Higher Chimney.

Unfortunately but few firemen employ this method. They usually prefer to load the furnace with a large amount of coal, producing a condition illustrated by turning up the wick of the lamp, which makes it smoke badly. As the fire in the furnace burns down, as represented by turning down the wick, it reaches a point where it does not produce smoke. Then by turning down the wick still lower, we get a condition which represents a fire burning too low for economy,—too thin and too much cold air going through it,—and which dilutes the gases and chills the furnace. Following the usual furnace performance from this point, the steam pressure then begins to drop and the fireman thinks it is about time to load up the furnace again. This operation is repeated time after time, a large amount of smoke being made each time, while if the firing was light and often and the fire was kept thin, with the dampers open, much better results would be obtained both in economy of fuel and

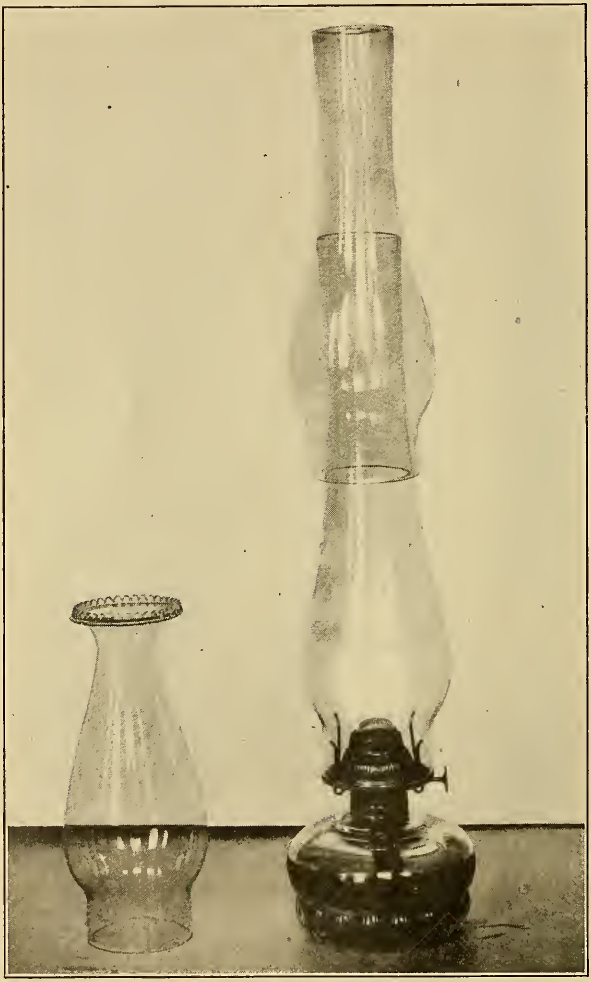


Fig. 7.—Very Large Clear Flame, Due to Extra High Chimney.

smokeless combustion. We might consider in this case that the draft at the fire would be equal to 0.1 in.

I will now change the chimney on the lamp. The one I am taking off is about 8 in. high, and the one I am putting on is about 10 in. high. You will notice at once a decided change in the action, as the wick now may be much higher, producing a whiter and better light and more of it without making smoke.

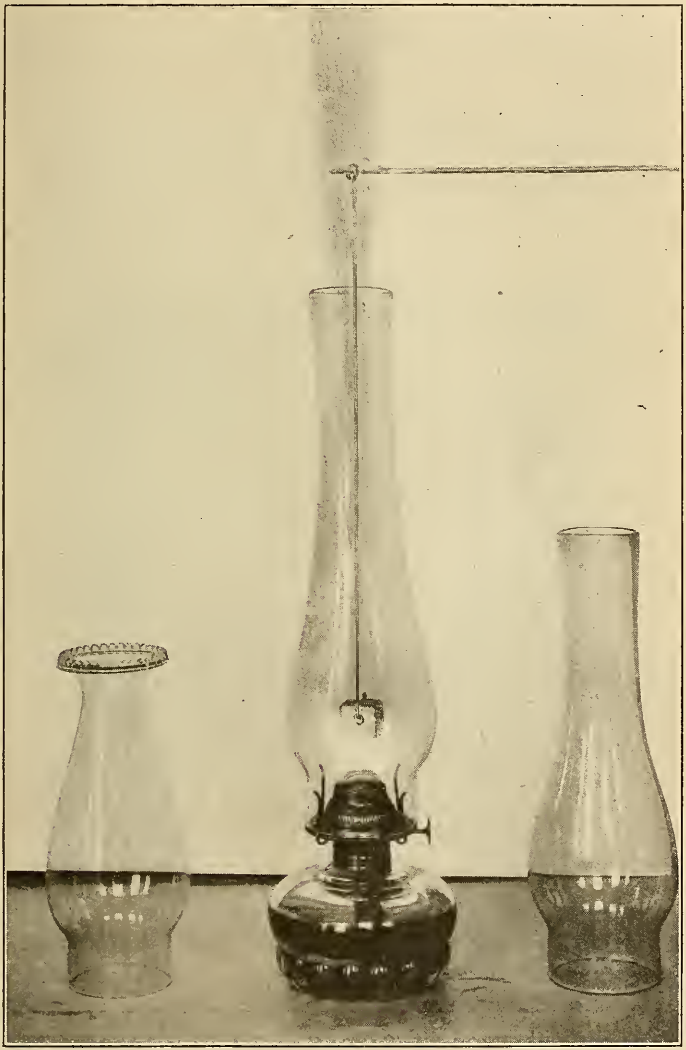


Fig. 8.—Smoke and Incomplete Combustion Caused by Chilling of the Flame.

This may be considered as analogous to running a furnace with about 0.2 in. draft. Under this condition more air is brought through the furnace, more coal can be burned per square foot of grate, and more horse power can be developed in the boiler, with greater freedom from smoke.

If we desire more power from a boiler we put a larger fire under it and evaporate more water in the same interval of time. So, to illustrate, I will turn the wick still higher until the lamp with its 10 in. chimney again begins to smoke. Now we will remove the 10 in. chimney and put on one 14 in. in height. The smoke again ceases and the flame is larger and brighter than before, showing that more air is brought through the furnace, the combustion is more rapid, and better results are obtained. This represents a draft on the furnace of about, say 0.25 in. I now turn the wick of the lamp higher again, till with this 14 in. chimney it again begins to smoke. We will now put the 10 in.

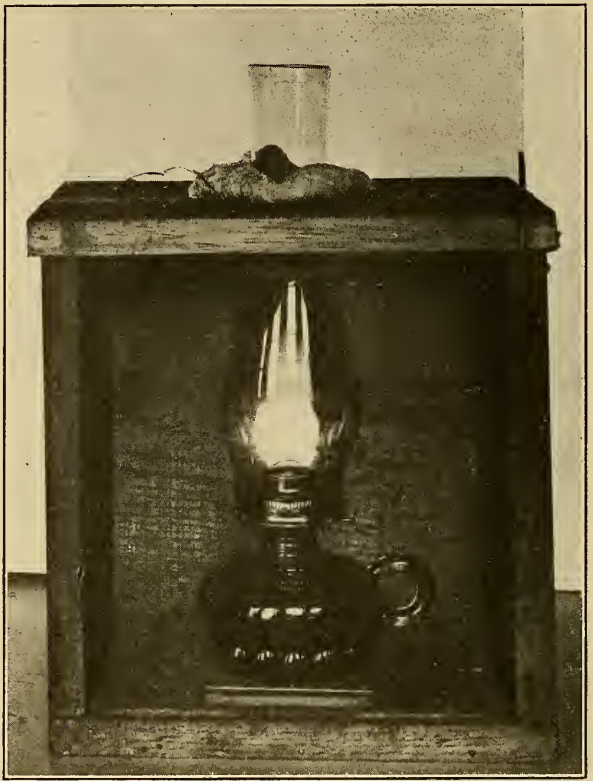


Fig. 9.—Lamp in Box Burning with Large Clear Flame, the Glass Front Open, Affording an Unobstructed Air Supply.

chimney over the 14 in., making a new height of about 20 in. The smoke again ceases, the flame is now enormous in size and very white in color, showing very rapid combustion and very high temperature—probably from 2,200 to 2,400 degrees,—while the one that we started with at the beginning, which burned like a torch, was probably not more than 1,500 to 1,600 degrees.

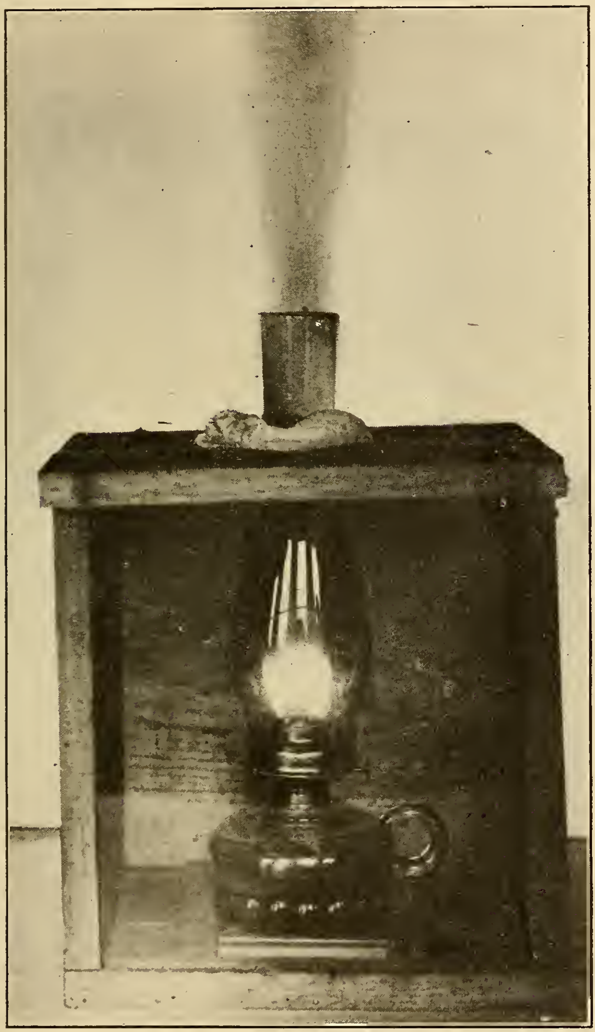


Fig. 10.—The Same as in Previous View Except That the Glass Front of the Box Is in Place, Obstructing Air Supply to the Lamp, Except Such Amount as Gains Admission by Leakage at Joints.

These experiments show that if a proper draft is provided for a furnace much more heat can be developed from the same amount of fuel burned than if the draft is low. The limit on draft over the fire is 0.3 in. or 3.35 inch. This is as high as practical in usual stationary practice, as more draft than this will burn holes through the fire. We should strive, in proper furnace practice, to maintain a draft from 0.25 in. to 0.30 in .and keep the fire from 4 in. to 6 in. in thickness. Furnace temperature should be as high as possible, which will insure the uptake temperature being at a minimum.

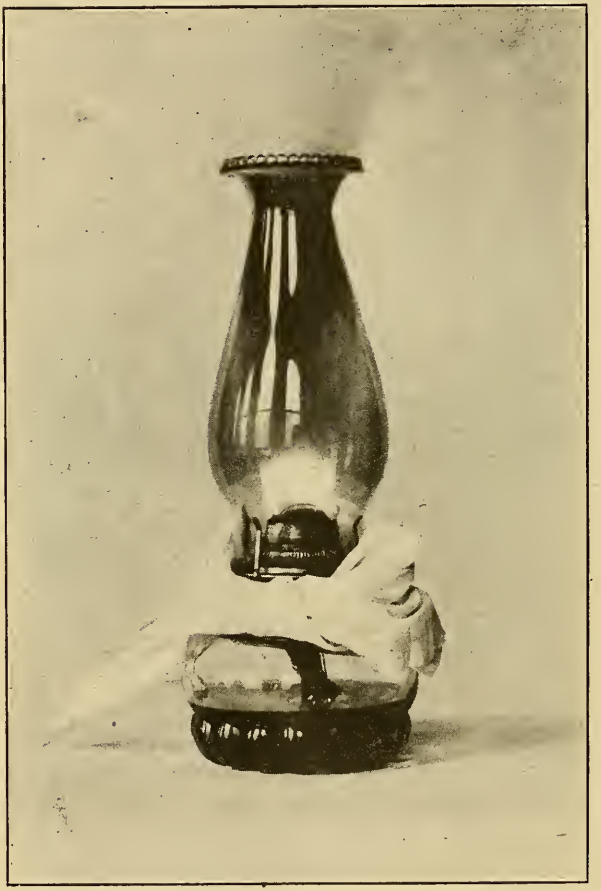


Fig. 11.—Showing Effect of Stopping of Air Supply from Below by Means of Handkerchief—Analagous to Closing Ashpit Doors of Furnace.

Boilers and furnaces are of many designs, some vastly different from others ; so, to give the best results, they should be handled differently. One important thing, however, that all boiler furnaces should have, is a combustion chamber between the grates and heating surface. In the case of this lamp, though the flame is burning brightly and making no smoke, if I drop an iron body down the chimney so that it comes in contact with the flame, smoke results. The cause is that the gases are cooled before the combustion is complete, as occurs when grates are located too close to the heating surface of a boiler, making it almost impossible to operate without smoke under such conditions. The foregoing has reference more particularly to the handling of the air, after it has been supplied to the fireroom.

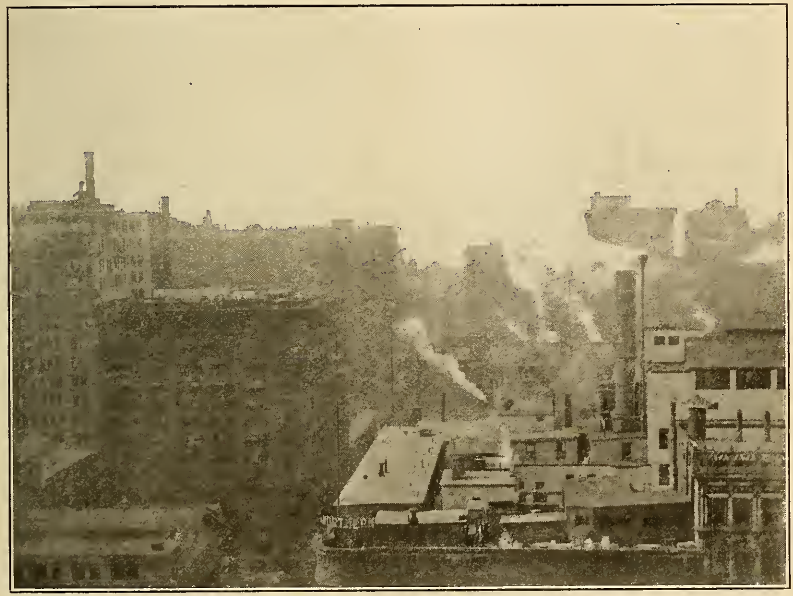


Fig. 12.—Representative View North from Fisher Building, Showing Absence of Smoke from Chimneys in Downtown District of Chicago.

The matter of introduction of air to the fireroom is of equal importance to its supply to the furnace, as we shall see by the continuation of my experiments. To illustrate, I will place the lamp, which is burning brightly, inside of this box which has three sides closed and the front open. At each side of this opening are grooves which will allow a sheet of glass to fit practically air-tight. We will place a cloth around the lamp chimney, closing the space where it passes through the top of the box. Then we will lower the plate of glass in the grooves and reduce the air supply to the lamp, with the result that the flame, which was bright before, now at once becomes red and bursts into smoke. This represents a condition which prevails in Chicago today during cold weather in nine-tenths of all of our boiler plants. Doors and windows are kept shut to keep out the cold, and the only air the fire gets is what comes in through cracks and crevices, and while the doors are being opened and closed for admission and exit of persons. It is no wonder that the doors in our buildings open hard, that the windows leak cold air, and that the offices are hard to heat, because the boiler plant in the basement is trying to get air, and in doing so is drawing a vacuum on the whole building.

One cold morning when I arrived at my own plant they were having a hard time to heat the building. The telephone was constantly ringing from different offices, giving complaint that the rooms were cold. I started an investigation. My assistant engineer told me that an inspection of the whole building had been made, and that only three or four cold radiators had been found, which had been remedied. He said something should be done to the windows, because they were leaking so badly it was impossible to heat the offices. I told him to open the door in the boiler room to the outside atmosphere, so that the furnace could get air. As soon as he did this, the trouble ceased in twenty minutes. The offices warmed up, the windows stopped leaking, and the front doors opened much easier than before. Architects and consulting engineers; in laying out buildings and boiler plants, seldom provide openings for air supply to furnace rooms.

Although we may have an abundance of air in the boiler room and sufficient draft, we may still make smoke if the furnace is not well designed and properly operated. To the operation of hand-fired furnaces the following will apply:

Fire light and often. If the draft is weak, the fire must be kept much thinner than if it is strong, as the resistance through a heavy bed of fire is much more than it is through a light one. Do not shut ashpit doors or close the stack damper too much.

If the equipment is that of mechanical stokers, treat it as a stoker outfit and not as a hand-fired outfit. Allow the stoker engine to do its part. It is there for that purpose, and can do a better job of firing than can be done by a man. It will put the fuel into the furnace constantly and uniformly, and will discharge the refuse the same way if properly adjusted. The furnace should not be open half the time for the fireman to poke the fire, for if it is, the green coal will get down on the bottom and the ashes and clinkers on top of the fire.

The exhaust of boiler feed pump, as well as that of stoker engine, should discharge into the ashpit. This will keep the grates cool, make the clinker soft, assist combustion, and help maintain a clean fire.

A damper regulator should be attached to both the stack damper and the throttle of the stoker engine. It will prevent the safety valve blowing and will regulate the speed of the stoker engine according to the amount of power required from the boiler. The more steam that is taken from the boiler, the faster the stoker engine will operate and the more fuel will be fed to the grate. The less steam taken from the boiler, the slower the engine will run, balancing the amount of coal in the furnace with the proper requirements. The damper regulator will work the same one day as it will another; it is attending to business all the time; it will stop smoke and save coal. In the plant I operate, the damper regulator described has saved a ton of coal every twenty-four hours, in addition to maintaining a steady steam pressure.

The gas analyzing instrument and the draft gauge are to the boiler what the indicator is to the engine. They will show where the trouble lies and how it may be remedied. If the CO_2 in the uptake is from 12% to 14%, conditions are good; if down to 3% or 4%, as in many cases, conditions are bad.

Mr. T. J. McNeill (of Reid, Murdoch & Co.): I have had experience with the smoke problem in the down-town district for about ten years, and at this particular time I think I am somewhere within the law, if absence of notices and suit from the Smoke Department means anything; but perhaps I had better not boast. It is largely, however, a question of conditions. With different conditions I might get different results. But I have been very fortunate in the last two or three years. I am making at this time a very small amount of steam compared with some of the other plants down town, as we have moved our factory to Hammond, Indiana, where we can make all the smoke we wish. Here in Chicago we are making, with two Babcock boilers, twelve to sixteen thousand pounds of steam an hour. I am pleased to say that we are getting along nicely, and from my experience I think that smoke can be eliminated through the proper design and construction of boilers and furnaces.

Mr. William Starr (of Pettibone, Mulliken & Co.): My experience might not be such as to be of help in the down-town district, because we have almost ideal conditions. We have a new plant and are above the ground. We have plenty of air coming into the boiler room, plenty of high chimneys, a fair height of boilers over the grate, and all conditions are good. So far, I have had no experience with the Smoke Department in any way. When we started up some six years ago we did not smoke, because the plant was started as a hand fired plant, with steam jets over the grate. As the business increased we put in chain grates. The chain grates are set about one-half in front of the boilers, which are of the Heine type, with tile roof.

At one time, I think for about three or four days, I noticed the chimney smoking a little. I let it continue for three or four days without saying anything, and then asked the fireman what the trouble was. He commenced making excuses, stating that the conditions were so and so, and that there ought to be some changes made. I said: "The conditions are the same as they have been, but if necessary I will make some changes, and the first change I will make will be a change of fireman." From that time on there was no smoke, showing that ordinary attention will operate such a plant as ours practically smokeless.

With our 200 ft. chimney, we get on the average about four-tenths of an inch draught at the fire. That we control, according to requirements, by a damper regulator; the regulator is so arranged that it does not close all of the draught, but is so set that we have at all times from 0.10 in. to 0.15 in. of draught, and for this reason the chimney does not smoke when the damper is checked.

Mr. W. G. Lighty (of the Schiller Building): I have been very much interested in the discussion. I believe that there has been a great deal accomplished in the last two or three years, especially in the down-town district, and I believe that a large portion of the results are due to the interest taken by the operating engineers, although I think much more could be accomplished if every engineer would take up the matter of educating his fireman. I thing that this is one thing in which we are especially lacking in Chicago,—that of good, experienced firemen.

As far as the present smoke laws are concerned, I have no criticism to make. But there is a matter of which I wish to speak. The ordinance provides for the examination of plans of furnaces as put in, but it does not provide for any examination as to the way plants are kept up and maintained. I believe that inspection of this character would be beneficial. For example: we may have a furnace installed with the approval of the Smoke Department, but in the course of a year or two, or less, it is found that conditions have changed so that it is necessary to work the furnace harder, or alterations may be made in the furnace that the Smoke Department have virtually no way of finding out about.

Mr. W. F. Strickler (of the Coated Board Co.): Being the engineer of a plant out on the North Pier, with I believe the most prominent chimney in the down-town district, which has been heralded in all the newspapers as the most notorious smoker in the city, I would like to say a few words about this six minutes time limit in the ordinance, for this time limit in a manufacturing plant I maintain is impracticable. In my own case there are times every week when I will lose 50% of my load through an accident in the mill. We run twenty-four hours a day, and accidents will occur. If I lose 50% of my load, we must choke fires, our furnaces will become cool, and, as

Mr. Saxe explained a few moments ago, the temperature must be kept up to run it. Now, suddenly the load comes on again, and we must meet it, but we cannot get back to normal conditions in six minutes. Again, we may blow out a tube once in a while, or an arch falls in, and we must fire an idle boiler, and I do not think anybody will claim that an idle boiler can be fired up and put in commission in six minutes.

I think the Smoke Department (and they have been following me up pretty closely) will bear me out in my statement that I have made a very great effort to stop the smoke, and have succeeded in cutting out 90% of it. I make the statement here tonight that my plant runs 95% of the time smokeless, and that not more than 1% of the time is it running in violation of the ordinance.

Mr. Donnelley, in his talk the other night, stated positively that the Department would prosecute anybody making two violations within a month. On the other hand, he made the statement that they would not prosecute anybody that is trying to do all that is possible to prevent smoke. He also said that railroads are trying to do all they can, so he will not prosecute them. There are others who are trying as hard as the railroads, and accomplishing, I maintain, more than they have accomplished. So it looks to me as if discrimination were being shown. I do not see why the Department should show greater discrimination in the case of railroads than it would in the case of paper mills.

Now, that six minutes clause allows a man to make smoke 8% of the time. I do not think that the Smoke Department will admit that there are many plants down-town which smoke 8% of the time, yet, recently (I think it was on the 26th of October) I had a couple of flues burst in one of the boilers and had to fire up an idle boiler. Of course I made smoke while I did it. On November 3rd I had an arch fall in on the grate, and I had to fire another idle boiler. On November 9th I received a notice from the Smoke Department that it had authorized the prosecuting attorney to bring suit against us for smoke violations on October 26th and November 3d. I think that if the Smoke Department is to use discretion and judgment as to whether a plant is doing all it can to prevent smoke, they should call and see whether we are actually trying to prevent smoke, or whether we are just trying to hoodwink them. I think an investigation would convince them that we are trying to do everything possible.

Mr. John Weber (of Hillman & Co.): I commenced to study the smoke problem and make experiments in the summer of 1888, while I was acting as the engineer of an electric light plant in the rear of the buildings at 31st St. and Indiana Ave., this city. The equipment, aside from the electrical apparatus and engines, consisted of two horizontal tubular boilers with common furnace settings and flat grates. While the business men and neighbors were delighted to see the establishment of an electric lighting plant in their vicinity, the smoke nuisance developed so quickly that those who were our friends at the start became our worst enemies.

With the assistance of several brick masons, a type of furnace was developed that with a reasonable amount of care in firing, eliminated the smoke entirely. Right here I want to add that the particular masons whom I found to be most proficient in the—let us call it—art, of suppressing smoke were either Englishmen or Cornishmen. As I remember, they seemed to work from varied experiences, and while they could suggest that this or that kind of an arch, or diverting wall, might do so and so, none of them had any data whatever to prove the assertions made. After installing about ten different kinds of settings, making experiments from 1888 to 1891, and searching the patent office records of the United States, we decided to have an attorney make a search in the English office. We were rewarded with quite an exposition of diversified ideas in furnace design, but found ourselves as far from the real meat of the subject as we were at the commencement. In building and operating some of these, we discovered that most any kind of a diverging wall, baffle wall, or arch seemed to reduce the smoke emanating from the stack when the wall or arch was new, or almost new, and the various air channels were open.

After the furnaces were operated for some time, the fire brick walls or arches became glazed over, the air channels became plugged up, and the efficiency of the particular furnace as a smoke preventer was almost, if not altogether, destroyed. One particular type that seemed to give the best results was a type of bridge wall with tunnels of proper area running lengthwise through the same.

A combination of air channels with this type of wall was patented by myself and my father in 1889, and this type was known as the *Weber Perfect Combustion Furnace.* A company of that name was formed with offices in the Lakeside building.

About this time the *Chicago Daily News* became interested in the fresh air work, with which most of us are acquainted. The Weber Furnace Co. effected an arrangement whereby a sketch or drawing of this type of furnace was advertised by the fresh air editor of the *Chicago Daily News,* and permission was given the general public to put in such an outfit.

It was found that with this setting the application of fresh coal had to be followed by the sprinkling of common gas-house coke over the green coal in order to ignite the green coal smokelessly. Many of these furnaces were installed when it was discovered that after some months of use the smoke inspector began to recognize the existence of the user. Our hopes were shattered and we realized that we were up against something we had not contemplated.

A German chemist was engaged to make a thorough investigation and give us some enlightenment as to why our settings proved so good at the start and gradually failed. As I remember the essence of his report, he said that the free carbon particles which are released from the coal in the first stages of distillation may be ignited if admixed with a certain quantity of air (which contains the oxygen that the green coal did not get in sufficient quantities while being heated to the ignition temperature), but that the admixture must be reheated in some manner before ignition of the new gas becomes a fact; that if the brickwork under the boiler is new, it absorbs and gives up heat rapidly and in giving up the heat it has absorbed while the fuel was incandescent, it reheats the new mixture of released particles of carbon and air and brings it up to the ignition temperature in its contact with the heated brick, to be burned in the combustion chamber; that after the brickwork has become glazed it absorbs and gives up heat more slowly, does not heat the free carbon and air mixture rapidly enough, and fails to ignite the newly distilled gas in consequence, which passes from the stack as smoke.

This will probably account for the numerous times that the owner has bought a furnace setting which worked long enough to warrant him in paying the bill for the installation and get soaked for a smoke fine afterward.

Since that time I have observed that there was a quantity of truth in the German chemist's theory, and I have noticed innumerable times that with a fresh brick setting, clean air channels, and a good fireman the problem of burning bituminous coal smokelessly is a fairly easy one,*but to obtain such a combination is not so easy.*

The man operating the fires is the largest factor in the whole combination, and the engineer who is responsible has often to render an account for the carelessness of the fireman. The chief engineer gets the diploma for carelessness in any and all events.

One great trouble I find in my experience with most employers is that after they get acquainted with the operating engineer who works for them, the advice and counsel given to the owner by the engineer is looked upon lightly and some outside influence and advice bears greater weight than the advice volunteered by the operating engineer. How many times does an owner make repairs to his boilers and elevators due to the reports of some engineer recommended by some business acquaintance, repairs that otherwise would not be made if they were requested by the engineer whose face the owner sees at the pay window every so often.

It seems to me that there should be a committee of operating engineers appointed by some one in authority to work with the Smoke Inspection Department and to have regularly appointed inspectors, who will make inspections of furnaces and offer suggestions to the owners of such furnaces that will enable them to do intelligently that which is right and proper, so that the owner may be obliged to make the repairs and be in a position to *rightly* blame the engineer or fireman for making smoke. The inspectors' reports could be referred to the committee of operating engineers for suggestions, drawings, layouts, and advice. The operating engineer should have a voice in the law that is intended to control and punish him. It is not right to make a law setting forth that six minutes of dense smoke in any one hour is a violation, when the quantity of fuel consumed under the stack is not taken into consideration.

The usually overworked operating engineer has one more task placed upon his shoulders, and the gravity of the task must be made to soak into the owner, and also the smoke inspector. To appoint a committee of engineers whose duty it is to act as advisers is apparently all right, but the kind of operating engineers appointed must not be of the sort that are in positions where they give their orders from a distance, occasionally and semi-occasionally; but rather the type of operating engineer who lives part of his time in or near the boiler room. If a corps of furnace inspectors existed who put on the usual boiler inspector's garb and went into the furnace room, say every three months at least, and made reports to the owners, together with good, solid, tangible suggestions, I think it would be a long step towards the solution of the smoke problem, and towards assisting the operating engineer to solve his portion of it.

It is very easy for the Smoke Inspection Department to write letters, notifying the owner that he has broken the law,—a law that does not take into consideration how much fuel is consumed under the particular stack,—and then have the owner call the engineer to his office and hand him a notice of suit with an air indicating that the engineer had committed murder. But it is a different proposition when you happen to be the operating engineer, and are obliged to depend on a certain class of men to stand between you and the manifestations on the top of the chimney, who are unable to understand what you want to teach them. If, for instance, the fireman was licensed by the Smoke Inspector to operate as a stoker of bituminous coal, and he should lose his license and his job if he became careless after the owner and the operating engineer had taken due precaution, do you think it would help matters? I think it would.

Mr. H. P. White (of Seipp's Brewery): There is one thing that has been neglected. I have heard no one speak of the matter of clean setting of the boiler. A lot of the trouble we have been talking about is occasioned by dirt. There are many engineers that do not keep their boilers as clean on the exterior surface as they should. If they will do this it will eliminate much of the smoke.

It would be a good thing if we had some way by which the fireman could get an idea of what is going out of his chimney. At present all he can do is to look into his fire; it may look fairly well to him, and still be making smoke. If there were some means whereby he could have a view of his stack,—something on the order of the recording smoke meter that is now on the market,—it would help the fireman to eliminate a lot of smoke. If he observes that he is making smoke, he will endeavor to learn the reason why. I think these suggestions are worth considerable thought.

Mr. A. D. Shriner (of Simmonds Manufacturing Co.): I am not prepared to say anything definite on the subject. I make smoke and I get a notice once in a while. Ours is a rolling-mill proposition. We do not know when we will have a load or when we will not. The six minutes time limit in the ordinance I think would justify some other provision, because there is not a person in the city of Chicago that has a range in his kitchen but that violates the smoke ordinance. Every time a fire is lighted, smoke is made for more than six minutes. We all understand that it takes four requisites brought together to make smokeless conditions,—space, mixture, time, and temperature. Unless we have the four together we are sure to make smoke, and it is pretty hard to get the four all together at the same time.

Mr. E. H. Perry (Sears, Roebuck & Co.): I have found out one thing, and if we stick to it I am sure we will do away with smoke; that is to complete the combustion of the fuel before the gases strike the heating surface of the boiler.

We have several conditions in our plant that are quite rare in Chicago. We have in the neighborhood of five or six hundred wagon-loads of rubbish, consisting of paper and boards, and this we have to burn. There are times when we make some smoke, we have done everything that we could to eliminate it, and I believe we have got as good a chimney as there is on the West Side.

Dr. I. R. Wolfinson (Treas., Smith, Barnes & Strohber Co.): We have had quite a little trouble at our plant, but we put in another boiler and changed the grates. Another thing we did was to put in a sky-light, so that the fireman could see when he was making smoke. The engine and boiler rooms are off to one side of the building, and that sky-light is put right over the boiler, so that all the fireman has to do is to look up through it at his chimney and he can tell right away whether he is making smoke or not.

Mr. C. F. Heal (of the Borland Building): I have been expecting since the last meeting to get a smoke notice, but so far I have not received it. I think the feature of the six minutes limit is one which interests most of the engineers. We cannot start up a fresh boiler without smoking more than six minutes. I was advised by one of the inspectors of the Smoke Department to fire up at night when we wanted to start a boiler. That would be violating the ordinance, however, even if the smoke were not seen. I would like to see the ordinance amended in this respect, so that we would have a little more leeway.

Mr. E. A. Norberg (of the Crane Co.): After hearing from Mr. Saxe, one would think that about the only thing you would have to do would be to install a stoker of some kind to prevent smoke. I used to think that myself until I began burning coal by stokers, and then I began to think that the way to prevent smoke was to take the stokers out. I believe that it does not make any difference to the stoker people how they are put in; they will install them in any manner as long as you have the price, and I know that they are sometimes put in so it will be an impossibility to operate the boilers without smoke. But I believe that boilers can be made absolutely smokeless; in fact, I have made one myself, and I should say that we cannot make smoke with this boiler if it is heated up and if the damper is left open. We have burned everything from screenings to block coal in it, and have never been able to make smoke after the boiler is heated up. I believe that if owners, when they install a new plant, would take the advice of their operating engineer more frequently, there would not be nearly as much trouble about this smoke nuisance.

We operating engineers spend two-thirds of our waking hours at the plant, yet some people think we know nothing about it. They will take the advice of a consulting engineer because he is supposed to know more about the problem than the operating engineer. I know that all the plants that are designed by operating engineers operate with a great deal less smoke than the plants that are designed by consulting engineers, and I believe the reason is that the consulting engineer is governed too much by the first cost. I heard a man say that the reason the plants in the city of Chicago do not operate right is because they do not cost enough, and I think that is quite true.

Mr. C. W. Brown (of the Armour Glue Works): The ground seems to have been pretty well covered, but there is one thing that I would like to speak of and that is fire brick. I think that the proper brick used in a furnace has as much to do with the chimney smoking as anything else. I believe that at our plant we made as much smoke as any plant in the city of Chicago up to within a few years ago, but under the pressure of the Smoke Department all that has been changed, and now I think we are complying thoroughly with all the requirements of the City. I notice that with a good quality of brick we are able to run our furnaces six to nine months absolutely smokeless, and at the expiration of that time, they will have to be replaced.

Mr. Edward Keenan (of the International Harvester Co.): At our plant we have done everything possible to prevent smoke. Most of our trouble comes from shavings, refuse, and twine, for that class of material is very hard to burn. We use all the way from 60 to 70 tons of shavings and saw-dust a day, and 180 to 225 tons of coal, and there are times when we get shavings faster than we can burn them. We have mechanical stokers, which have given very good satisfaction, and I believe this type of stoker is the solution of the smoke problem if it is put in right, handled right, and taken care of.

So far we have not been troubled much by the Smoke Department, although once in a while Mr. Bird will jog our memory by sending us a notice.

Mr. J. W. Mabbs, M. W. S. E. (of the Board of Trade): I would like to see the boiler furnace or stoker that can be fired up from a cold condition and not make smoke. It seems to me too, that it would smoke just as much when it is fired up after dark, as during daylight. What is the engineer going to do when he must fire an idle boiler? According to the law he must not make smoke more than six minutes in one hour. If he makes smoke more than six minutes twice a month, he is fined. Now, I would like to know from the Smoke Commission how much discretion is to be used in such cases.

I know of a recent case where a smoke device on a boiler went wrong, and the boiler began to cause smoke. The only thing feasible was to shut down, but the firing of another boiler would make smoke more than six minutes. There are many of these things that an operating engineer encounters which the man who built the chimney does not know anything about, or does not often take into consideration.

A suggestion was made at the last meeting which I think was an excellent one,—namely, that the Smoke Commission publish information that it obtains. This would be worth much to the engineers. The engineers, as a body, are heartily in favor of helping along the anti-smoke proposition, and I think there is not an engineer in Chicago but that will do all he can to help it along. At the same time there are a whole lot of things on the other side of the question. Often fires have to be cleaned. I should prefer to have half an hour once in ten hours when I could make smoke, than to have six minutes in each hour, because in half an hour I could have all our boilers cleaned, but it is pretty hard work to clean from one to six boilers and not make smoke more than six minutes. I admit that a furnace can be made that will not make smoke after it is started, but I have never yet seen one that can be fired up from a cold condition that would not make smoke.

Mr. Otto Luhr: It seems that most engineers expect furnaces to be fool-proof. Such a thing never has been and never will be. They will always require a certain amount of supervision by the engineer, including instruction of the fireman.

Mr. Saxe gave a very good demonstration of how to operate a kerosene lamp. A kerosene lamp is easy to operate, but a furnace, while the principle of its operation is the same, is more difficult to handle.

There is not sufficient stress laid upon the proper mixture of combustible gases and the incoming air. We have in most cases too much air going through the furnace, and whenever that condition occurs, the furnace temperature is reduced. Whenever we have sufficient air, we have high temperature as a natural consequence, but a proper mixture is not easily obtained. In order to get plenty of air through the furnace, all we need to do is to leave the doors open, or take the chimney off of the kerosene lamp as Mr. Saxe did, but we do not get it properly mixed. In a kerosene lamp we find a sieve underneath, which is there to admit the air in small streams; in other words, it acts as a mixer.

I think the Smoke Department has accomplished much by inducing engineers to set their boilers properly,—to put in an arch, for instance, and not let the gases come in contact with the cold surface right away, thereby securing a good mixture.

I gave this subject a great deal of thought some years ago, not because I wanted to, but because I had to. I have experimented a great deal, and have tested a great deal, and I had to instruct my own fireman how to operate the furnaces properly. It is not easy to instruct old firemen, for they generally fall back into their old habits. As a rule there are not sufficient instruments in the boiler room. In 95% of the boiler rooms there are no flue gas thermometers; the fireman does not know what he is doing for he cannot even see the chimney. The only guide he has is to look at the fire in front. Usually a fireman does not study the laws of combustion, so it is necessary for the engineer to study them, to instruct his fireman, and to show him how the furnace should be fired.

I will say this in favor of the Smoke Department, that it has done much to eliminate smoke. If I look back ten, fifteen, or twenty years in Chicago, I recall that we had a great deal of smoke, and owners could not be compelled to apply proper devices for suppressing it. Since the Smoke Department began compelling owners to do things right, we have eliminated the smoke to a great extent.

Of course, there are only three conditions that are required to produce perfect combustion,—sufficient air, high temperature, and proper mixture. If you get them you get perfect combustion. However, these conditions are not obtained easily, for how is the fireman to know whether he has sufficient air, just by looking at the fire? How can he tell whether, when the air enters the furnace, if it mixes properly with the gases? As it is now, he may know only by experience.

CLOSURE.

Mr. Paul P. Bird: The discussion of this paper has been so voluminous that there is but little that the author may add, and in most of it information of value has been contributed. I think that the most striking thing that stands out in all the discussion is in connection with the difficulties of smokeless operation of steam plants. Mr. McGrath's remarks about the early attempts made years ago to abate the smoke nuisance, and Mr. Bement's description of the various organizations and city officials who have joined in the smoke fight in the past, convince us that the problem is difficult and worthy of all the thought and study that we can give it. The fact that the discussion has been frank and to the point has pleased me, because it shows that every one is interested in the problem and is willing to do his share toward bringing about an improvement. Different engineers who have discussed the paper have made certain suggestions for improvement in the work of the City Smoke Department. In fact, after reading all of the discussions, the writer concludes that practically every suggestion that has been made could be carried out if there was more money available for the use of the Department. For instance, it was suggested that the Department should publish bulletins from time to time which could be circulated amongst engineers and every one interested, which might discuss various installations and illustrate designs of smokeless furnaces, boiler settings, etc. The Department has often considered this and would be very glad to do it if there was sufficient money available to pay for publishing and circulating the bulletins.

Similarly, it has been suggested that offenders should be notified at the time the smoke is being made. With the large number of chimneys and with the few outside inspectors to watch them, it has been found that it is entirely impossible to notify the engineers or owners of smoking chimneys at the time that the smoke is being made. The outside inspectors are able to cover so much more ground when they work as they do now, than they would under such a plan.

Mr. Bement, in his discussion, mentioned the fact that a great many chimneys smoke at night and on holidays that do not smoke at any other time, and that the Department should provide some means of preventing this. Again, we cannot afford to employ a night squad. Our appropriation only provides for fourteen outside inspectors, and we feel that there is so much work for them to do in the day time, that it is more important that they work at that time. The criticism is good, however, because we all know that many chimneys smoke at night and on Sundays, but during week days, when the smoke inspectors are at work, they are clean.

Mr. Johnson suggests that we extend our system of having experienced engineers, in the employ of the Department, visit the plants that make smoke and work with the engineer in charge toward discovering the cause of the smoke and eliminating it. Again the poverty of the Department comes in and keeps us from doing this. If we had sufficient men we would be able to have every violation that is observed followed up and the cause of the smoke discovered. The task of cleaning up the smoke of Chicago is such a big one that it would be possible to work a Department several times the size of the present one efficiently. With thirteen thousand chimneys which may sometimes make smoke, scattered over one hundred and ninety square miles, it would require a very large force to watch and follow up every violation properly.

Mr. Bement in his discussion outlined a certain classification of all stationary steam plants in Chicago which he suggested might be made. There is considerable of this classification and tabulation work that should be done by the Department if the men and time were available for the work. However, as in the other cases, our men are kept busy all the time on work that we feel is more important. In a few years from now the office possibly may make use of this classification or some other one. At the beginning of the Department's work, about two and one-half years ago, it was thought that all of the plants in Chicago might be grouped in various classes, and that the Department should hold plants in different classes up to different standards. Today, however, it is believed that this system is not the proper one. The policy of the Department for the last year has been to adopt a fixed rule in certain sections of the city, this rule applying to every plant and to every one in that section. In the central district, from Lake Michigan to Halsted Street and from Chicago Avenue to 22d Street, the *thirty-day rule* is now in force. This rule is, that whenever the records of the office show two or more violations by the same plant within thirty days, suit is started. The rule is enforced on all alike. The chimneys of all buildings, factories, locomotives, tugs, steamships, etc., in this district, all come under the same rule. It is believed by those in charge of the work that such a system is better than to group plants into different classes and have a different rule for each class. It may be harder to keep down smoke in a tug boat than it is in an office building, but both stacks are in the center of the city and the smoke from one is as much of a nuisance as the smoke from the other.

Two or three of the engineers who took part in the discussion felt that the six minutes of smoke that plants are now allowed to make in one hour, is too small a margin for use in the manufacturing districts or during the hour when fires are being cleaned. The author feels that six minutes is a liberal enough allowance when the manner in which the violations are observed is considered. If we were able to have men watch all the stacks in the city all the time, and suits were started on every violation of the ordinance that was reported, it might be considered to be too severe an ordinance. However, when one cannot even see a stack once a day I do not feel that the requirements of this ordinance are stiffer than advisable.

Mr. Naylor called attention to the smoke that is made by city buildings, such as the public schools and pumping stations. While it is true that these two classes of buildings are frequent violators of the law, it is also true that there has been a very great improvement in the smoke conditions at the school houses and pumping stations during the last two years. The schools in Chicago have not been as free from smoke in years as they were during the winter of 1909-1910. Similarly, with the pumping stations, they are making less smoke today than ever before. It is quite true that there is room for improvement, but it should not be felt that the City is not trying to stop its own smoke.

Mr. Naylor also felt that the City should compel the installation of automatic smoke recorders so that the engineer would have some means of knowing when his stack was smoking. I feel that, as long as smoke recorders are such newly devised instruments and have not yet been tried out under all conditions, it would be impracticable for the Smoke Department to consider such a rule. I am very much in favor of the use of smoke recorders and feel that in a great many instances, particularly in office buildings, devices of this sort are quite necessary. However, I do not think that the time has come when the City should compel the installation of such instruments.

In his discussion Mr. Bement has given some interesting data on the history of the smoke prevention movement in Chicago. It is desirable that this information be put on record, and I am glad that it has been presented in the discussion of this paper. He suggested two changes relative to the organization of the Smoke Abatement Commission. First, that one of the members of the Commission be an engineer, and second, that another one of the members should be a member of the city administration. These suggestions might make the Smoke Abatement Commission stronger in some ways, and yet I feel that it would be difficult to find a group of men who would be more efficient and more unselfish in their work than the members of the present Smoke Abatement Commission.

Mr. Bement also suggests that the ordinance be revised and thoroughly gone over. In my opinion, too, this should be done. However, during the past two and one-half years we have felt that as long as the ordinance allows us to go ahead with the work along the lines decided upon, it is better to let well enough alone and first get all of the plants in the city within the requirements of the present ordinance and then draw up another one.

June, 1910

WOOD PRESERVATION FROM AN ENGINEERIFG STANDPOINT.

C. T. Barnum—U. S. Forest Service.

Presented, October 6, 1909.

For a number of years engineers throughout the country have been confronted with the fact that the supply of timber for structural purposes is being rapidly exhausted, and they have been compelled to give serious consideration both to conserving the present supply and to developing other materials to act as substitutes.

That much energy and thought has been given to the substitution of other materials for wood is evident when we consider what has been accomplished. In this work the use of steel and concrete, both separately and in combination, has undoubtedly far exceeded that of all other materials. The vast quantity of reinforced concrete now used for all kinds of buildings and construction purposes, the amount of steel used for towers and poles in electric transmission lines, the number of steel and concrete bridges, and the growing popularity of steel for the construction of railroad cars, indicate only a few of the many ways in which these materials have been successfully utilized. Experiments are being carried on continually to extend these uses, and there is every reason to believe that much more will be accomplished. The effect of this substitution on the growing demand for structural timber is enormous, but in spite of this successful substitution the demand for wood as a structural material has steadily increased from year to year. In illustration of this increasing demand for timber, the Forest Service estimates show that the lumber cut of the United States increased from eighteen billion board feet in 1880, to forty billion board feet in 1907. In view of these figures it is safe to assume that it will be a very long time before we find ourselves able to do without it.

There is another factor to be considered in the substitution of inorganic materials for wood. The limited supply of these materials must be kept in mind. Iron, for example, once taken from the mine is gone and cannot be renewed. Wood, on the other hand, is capable of growth and hence of indefinite replenishment from the same area. This fact will cause metals especially to rise in value, so that the ratio of cost between them and wood for construction purposes is a sliding and ever-changing one.

It is to be regretted that the energy which has been devoted to conserving our wood supply has not been equally as strong as that devoted to finding wood substitutes. Why it has not met with the same consideration is hard to determine, but the fact remains that in view of its importance only indifferent attention has been given to it. For certain classes of construction wood is, on account of its inherent properties, best adapted for use, and it has so far resisted all attempts to displace it.

For railroad ties, telephone and telegraph poles, piling, mine props, and structural lumber, wood has shown its superiority. The extensive use of other materials for these purposes, of course, cannot be overlooked. Steel and concrete railroad ties, reinforced concrete and glass poles, steel and concrete piles and mine props are instances of this. In 1907, 572,233 steel ties were sold by one company. This company claims that the steel tie is no longer an experiment. Very much the same progress has been made with other forms. Reports from various users of this material, however, show that uncertainty of successful substitution still exists and the general impression throughout the country is that considerable more experimenting must be done before satisfactory substitution is accomplished.

This brings us back to the consideration of our timber supply for use in these particular cases, and when we consider the amount of wood consumed here its importance is seen to be justified.

Census statistics shows that in 1907 the steam and electric railroads of the country purchased some 153,000,000 cross ties, the telephone, telegraph, and other electric companies purchased over 3,500,000 poles, and it is estimated that throughout the mines in this country over 170,000,000 cubic feet of round mine timber was used. There are no reliable figures to show the production of timbers intended for use in the construction of bridges and for use in piling, but it is estimated that for the latter at least 2,000,000,000 feet were used. When we consider that these products constitute less than one-fifth of the total volume of lumber cut we get some idea of the enormous drain on our timber resources. It is further esimated by the Forest Service that the rate of cutting at the present day is exhausting our resources at the rate of about three times their growth. It is quite evident, therefore, that unless some radical changes be made a serious shortage of structural timbers is inevitable. This is especially true of the harder and more durable woods. The supply of this better grade of timber, which through its own properties resists decay for a reasonable time, is rapidly waning and in consequence its price in the market is rising. The average price of white oak, for instance, increased at the mill from $13.78 per thousand feet in 1900 to $21.23 per thousand feet in 1907, or 59 per cent. Leading lumber dealers, railroad managers, mine superintendents, and other consumers of timber for structural purposes, are accordingly turning their attention to ways and means of substituting cheaper and more plentiful kinds of timber for the better and more durable grades. Thus, where specifications once rigidly insisted upon first quality white oak for ties, or heart longleaf pine for dimension stuff, they are now given a very liberal interpretation, and other species than white oak are accepted with no difference in price, or considerable amounts of sapwood are allowed on "all-heart sticks."

This deterioration in quality naturally results in a decreased length of life, which in turn compels a large annual cut of timber.

TREATMENT

A feasible and effective way of relieving the situation is by the treatment of the timber to protect against decay. A successful treatment of this sort, provided the cost can be kept within economical limits, will, in the long run, not only greatly decrease the cost to the consumer, but will also tend to decrease the annual demands on the forest. A proper preservative treatment will prolong the life of decay-resisting species as well as those of an inferior grade. If all ties, poles, posts, piling, mine props, shingles, and structural lumber adapted to treatment were given an efficient preservative treatment, an estimated annual saving of five million board feet would ensue. The practice of preservative treatment will also create a new and increasing market for many timbers not formerly used, and timber consumers will more easily break away from their former custom of adhering closely to a few well-known kinds and disregarding others which may be equally as good in other respects but lack durability. Moreover, there will be an increasing realization that by the use of cheaper woods properly treated with preservatives, as good or better results can be obtained, together with the reduction of the annual cost. This last item, the saving in dollars and cents, is the all-important factor of wood preservation. As soon as the consumer fully understands that his annual expenses can be actually reduced by these methods, it is only natural to conclude that a strong effort will be made for their adoption.

Wood preservation is an exceedingly complex subject, and upon considering it many problems arise for solution. There has been a great deal of thought given to it, and it has undoubtedly made rapid strides during the comparatively short time it has been practised in this country. Nevertheless, it is still far from being on a sound scientific basis. The experiments that have been made show very clearly that each different species of wood, and wood of the same species but differing in the character of growth, present an entirely different set of problems. They differ greatly in the receptibility of different preservatives and they differ in the kind of preparation necessary for treatment and in their action in contact with the preservative, and after. The kind and condition of wood to be treated and the conditions under which it is to be used are very important factors in determining the kind of treatment that is best. The effect of the preparation and of the preservative on the mechanical properties of the wood are also very important, and must be carefully considered before any treatment is decided upon. Present practices are now largely determined by the experience derived from preceding years rather than an intimate knowledge of the theory of the subject. This latter feature, however, is most important and is at the present time receiving much deserved consideration. The Forest Service in its laboratory now being erected at Madison, Wis., expects to study very comprehensively the different theoretical questions arising in this work, and it is hoped that this will result in extending our knowledge of the action of different preservatives and the way they should be applied to each species of timber to secure the best results.

During the early period of wood preservation in this country, the expense of the treatment and the necessary apparatus and the lack of reliable information regarding the results prevented to a great extent its extensive adoption. As the demand for it increased and more reliable figures were obtained regarding the actual increase in life from various treatments, the economic results were better understood. This led to a larger development, and at the present time there are over sixty wood preserving plants operating in the United States, with an output, in 1907, of one and one-fourth billion feet.

PRESERVATIVES

Of the many antiseptics which at one time or another have been proposed for the preservation of timber, two different classes may be made: (1) Antiseptic salts and various substances, such as zinc chloride, corrosive sublimate, and copper sulphate; and (2) antiseptic oils, of which creosote, or dead oil of coal tar, is most generally used. The most common preservatives in general use are zinc chloride and creosote, and both are excellent antiseptics. It may be said, however, that the prinpal value of zinc chloride is its cheapness and its ease of transportation, for it can be hauled in the form of a solid and dissolved at the treating plant. The principal defect of zinc chloride is its liability to leach out of the timber when exposed to moisture either in the soil or in the atmosphere. It readily dissolves in water and so its subsequent leaching out is merely a question of time, and the wood is left once more subject to attack. Its use, therefore, is limited to less moist situations. Creosote, on the other hand, is practically insoluble in water, so when a high grade of oil is used and injected into the timber, decay will be postponed almost indefinitely. Its principal disadvantages are its higher first cost as compared with zinc chloride, and its limited supply and the subsequent difficulty in getting a good grade.

In treatments for many structural purposes, such as piling and timber in wet situations, and especially where a long life is desired, creosote undoubtedly has demonstrated its ability to give the best results. Upon examination of certain timbers that have resisted decay for a long time, it has been learned that it is the heavier constituents of the oil that have remained in the wood, and it is therefore concluded that these constituents are to be depended upon in preservation work. For this reason, it is considered advisable that when specifying for creosote the heavier fractions should be called for.

TREATING PROCESSES

Treating processes as practiced today may be divided into two general classes: those which use pressure, and those which treat without pressure. Both of these may be subdivided into what is known as full cell and empty cell processes. The pressure process is too general and too well known to need description here. It is the more widely used of the two and without doubt the more effective for work on a large scale, and where a variety of woods must be treated. Pressures above 175 lb. per sq. in. are seldom exceeded in these plants, as with proper preparation practically all woods can be treated with this pressure, and for many woods less is needed. The quantity of treated wood required determines the volume and size of the apparatus used and its cost. A plant of this kind having a capacity of about 3,000 ties per day would cost about $40,000 to install. Within the last year or so there has been introduced a plant in which only a medium amount of pressure is used. This type may be called a medium pressure plant. In it pressures ranging from 50 to 100 lb. per sq. in. are used. It is principally adapted for use by mining companies or city traction companies, where woods of a porous nature not especially resistant to the entrance of the preservative are used. Such a plant would usually be of a much less capacity than the ordinary plants, on account of being designed for the treatment of special classes of timber for local use, and can be built more cheaply on account of being of lighter construction. A plant of this type, with a capacity of 1,500 ties per day, would cost, approximately, $20,000 to install.

Plants which treat without pressure are rightly called non-pressure plants. This type of plant is not the open-tank proper like that used in the treatment of butt telephone poles, but a closed cylinder similar to those of the pressure and medium pressure plants, but made of very much lighter material, usually ¼ inch iron. The Forest Service has done much to develop this latter plant, because this process has filled a real need, a need which the pressure process could not fill. The development of this non-pressure process is due very largely to the heavy expense involved in the purchase and installation of the pressure plant, an expense which confines such plants to large commercial companies or to companies such as railroads, which demand a very large and fairly constant supply of structural timber, comparatively resistant to the entrance of the preservative. It is not to be understood that this non-pressure process is to replace in any manner the older and more firmly established pressure processes for all timbers and conditions.

What was needed was a process by which the more porous lumber of different kinds and for different conditions could be treated efficiently and cheaply in a plant inexpensive to install and simple to operate. The record of attempts to meet this need is the history of the non-pressure process. This type of plant generally has a treating cylinder 6 feet in diameter and about 50 to 60 feet long, and a capacity of about 500 ties per day. It may be completely installed for from six to eight thousand dollars.

For the butt treatment of telephone and telegraph poles an ordinary open tank, either rectangular or round, about 9 feet in diameter by 9 feet deep, and fitted with steam coils, is used. A storage tank of small capacity for holding a supply of the preservative, and a jib crane for handling the poles in and out of the treating tank, complete the equipment. Such a plant can be installed for eight or ten hundred dollars.

A full cell treatment or process occurs when the wood cells and intercellular spaces of the timber are completely filled with the preservative. The portion of the timber treated in this case is made to take as much of the preservative as the cells are capable of containing.

On account of the expense involved in a treatment of this kind, with a preservative as costly as creosote, means have been sought to remove from the timber a portion of the preservative injected. In this manner the same penetration is secured with a much less amount of the preservative, and the cost of the treatment is consequently decreased. In treatments of this kind the preservative contained in the cells proper is withdrawn, and the cell walls left simply coated or painted with the preservative. This process is used largely in treating railroad ties with creosote, where mechanical wear destroys them before the increased life to be derived from a full cell treatment can be obtained.

LENGTH OF LIFE

The length of life of treated timber, like the treatment, depends on a variety of conditions. The kind of wood, kind of preservative used, the kind of treatment given, and the conditions under which the treated timber is used; all have an important bearing on the length of life. In the southern states, Louisiana and Texas particularly, a loblolly pine tie untreated will last little more than a year. Ties treated with zinc chloride and placed in a track in the same locality have been removed in three years on account of decay. The life of the same species of timber in one section of the country will not be the same when exposed to the climatic conditions in another section. The use of zinc chloride as a preservative does not give as long life as creosote. Ties properly treated with this can, however, be made to give an average life of about 12 years. In the Central West, hemlock and tamarack ties treated by the Wellhouse process have shown a life of twelve to fourteen years, while untreated ties under the same conditions have to be removed at the end of four years on account of decay. Properly creosoted ties can be made to last until destroyed by mechanical wear, and if protected against this wear can be made to give 20 to 30 years' service. With the proper kind of treatment, a pile can be made to last from twenty to twenty-five years. The L. & N. R. R. Company in 1882 used large quantities of creosoted piles, stringers, and caps in the construction of trestles and docks in the vicinity of Pensacola, Fla. All of this material gave a service of over twenty-five years. The New Orleans and North Eastern Railway Company's bridge across Lake Pontchartrain is another notable example of the efficient service to be expected from a good treatment. This bridge was built in 1876 on creosoted piling most of which today is in a good state of preservation. Most of the timber used in these instances was southern pine which, if untreated, would be destroyed by marine borers in 3 years or less. At Girardville, Pa., in the Reading Coal Company's mine, treated timbers have given 12 years' service where ordinarily they would be removed in 2 years.

The Forest Service has estimated that proper preservative treatment will increase the life of ties over 200%, poles 100%, posts, 300%, piles 700%, mine props 400%, and lumber 300%. These figures are made up of the average estimates of treated and untreated life for the various forms all through the country and under all conditions, so they naturally give merely an indication of the results of treatment which, in specific instances, may be much more or less than the general average.

ECONOMIC CONSIDERATIONS

It has been clearly demonstrated that the life of timber in many situations has been increased at least two-fold by the use of preservatives, and often the increased life is very much greater. Suppose, for example, that certain timbers put to a certain use will last 5 years without treatment. Disregarding interest charges, it is therefore true that the cost of treatment must be less han the additional cost of new timbers 5 years later, plus the cost of their setting in order to effect a saving. In treating on a large scale the additional cost of any treatment now practiced does not usually exceed the present purchase price of the timber. Therefore, the saving means at the least the cost of resetting the timbers, plus the advance in price of the timber, over a period of 5 years. For example, the popular grade of mine timber in the West has increased some 40 to 50% in price within the last 5 years, and it is reasonable to suppose that a corresponding, if not greater, increase will occur within the next 5 years. Therefore, the financial saving from a treatment, which will double the life of the timber, will be equal to the cost of replacement, naturally a variable quantity, plus 50% of the present cost of timber. More frequently a good treatment will triple and quadruple the life, and the financial saving is correspondingly greater. Another factor entering into the economic value of the treatment is that often replacement of timber is an expensive undertaking. It means in some cases a shutting down of work on hand during the period of replacement, with the consequent more or less serious financial loss. For instance, the replacement of the timber in a mine shaft will often partially, if not wholly, stop all the work through that section during the period of replacement, with a corresponding financial loss to the company. Since by treatment these replacements may be easily reduced by one-half and oftener to a greater extent, it can be seen that this element bears an important relation to the financial saving growing out of preservative treatments.

With railroad ties a wide field for the betterment of conditions exists in the more general introduction of preservative treatment. Formerly, white oak was the most popular and widely used species for this purpose, but in the past 10 years the cost of the oak tie has more than doubled, and railroads have consequently been turning their attention to other species. Thus loblolly and shortleaf pine in the South, hemlock and tamarack in the Lake States, lodgepole pine and Engelman spruce in the West, birch in Wisconsin and the New England region, and maple and beech in Michigan, Pennsylvania, New York, and Vermont, are gradually attaining recognition and rarely fail, when properly protected from decay and mechanical wear, to give satisfactory results. For example, it has been estimated by the Chicago and Northwestern Railway Company that the cost of the average untreated hemlock or tamarack cross-tie, when laid for use west of the Mississippi, is 75 cents. The cost of a satisfactory impregnation with zinc chloride is about 12 cents per tie, making the cost of the treated tie 87 cents.

The annual charge on an untreated tie costing 75 cents is 16.8 cents. For a treated tie costing 87 cents and lasting 6 years, the annual charge is 16.6 cents; lasting 7 years, 14.5 cents; lasting 8 years, 12.8 cents; and 10 years, the estimated life of a treated tie is 10.7 cents. These figures demonstrate that an added life of a single year makes the cost of treatment practicable and an added life of 5 years (a conservative estimate) secures a saving of 36.3% in the annual charge. By the substitution of a creosote for the zinc chloride treatment, although somewhat increasing the initial cost, the tie can be conservatively counted upon to resist decay for 18 years, and this added length of life will amply repay the extra cost of the treatment.

By proper preservative treatment and the prevailing rates of interest, it can be conservatively estimated that the net annual saving for each form treated would be about 3 cents for a tie, 9 cents for a pole, 1 cent for a post, 2 cents for mine props, and about 50 cents per thousand feet for lumber. This would result in a total annual saving of about $71,780,000. This includes the cost of labor as well as that of the timber itself, and this represents the amount of money that could be turned each year into other channels if wood preservation were uniformly adopted throughout the United States. It must be remembered, of course, that these figures are made up of average estimates of untreated and treated life, and naturally cannot be applied to specific cases.

Wood preservation, then, accomplishes three great economic objects: (1) It prolongs the life of durable species in use; (2) it prolongs the life of inferior and cheaper woods and thus enables the utilization of those inferior woods which, without preservative treatment, would have little or no value; and (3) it reduces the annual charge and renewal charges whenever it is used, enabling the money saved to be put to other uses.

DISCUSSION.

President Allen: The establishment by the Forest Service of a laboratory for testing processes and materials for wood preservation is certainly an important step in the art. So far, such experimental work has been carried on by different interests in various parts of the country and the results have often been limited by lack of resources. It will certainly be a great privilege to be able to call on a central experimental plant, where efficient apparatus has been installed, and where all kinds of preservative materials and woods are available for use. Of course it is too early now to speak of the results; these will depend on the way the station is operated and largely, as Mr. Barnum has said, on the coöperation of engineers and users of timber generally.

Several papers have been presented before this Society in the past on the subject of wood preservation. The first one was by Mr. Samuel M. Rowe, in 1899, and Mr. Octave Chanute presented one in 1900. Mr. Chanute is with us this evening, and I am sure we shall be very much pleased to have him open the discussion.

Octave Chanute, HON. M. W. S. E.: I have listened with much interest to Mr. Barnum's paper. After an experience of some 24 years in the preservation of wood, I will say that results depend largely upon the thoroughness with which the work is done. When we began work along this line the results obtained were not nearly as good as those we are obtaining today, simply because we had not had the necessary experience. We followed at that time the German practice of injecting about one-third of a pound of chloride of zinc to the cubic foot of timber, and an average life of 11½ years was obtained with hemlock and tamarack ties. Since then we have ascertained that the Germans, in their extended experience, have increased the dose to one-half pound of dry chloride of zinc to the cubic foot, and with that we are now obtaining results (only 10 years old, however) which promise a life of 14 to 17 years in the track.

We also found that in the early days we treated the ties too soon, and did not allow them to be sufficiently seasoned to become entirely saturated throughout with the antiseptic treatment. I feel confident now, with the knowledge we have acquired, that we are going to get results with zinc-treated ties which will compare favorably with, although they will not equal, the results to be obtained with creosote. If creosote be thoroughly injected into wood with the full-cell process, the results which have been obtained in Europe show that a life of 20 to 27 years can be obtained. But there is one element there which does not obtain in this country. The rolling stock on the European railroads is light; the weight per wheel is limited to about 10,000 pounds, while the weight of our modern freight cars is much greater, for instance, a car weighing 49,000 pounds and carrying 100,000 pounds will give wheel pressures of about 18,000 pounds per wheel. Those weights are all producing mechanical wear, so that the ties, whether treated with zinc chloride or creosote, are going to be destroyed by mechanical wear sooner than by decay. Therefore, the problem of preservation also brings up the problem of better track, which I hope will be given due attention by the engineers of railroads.

D. W. Roper, M. W. S. E.: With regard to wood preservatives of various kinds, I would inquire if any of the preservatives mentioned have any active chemical properties which might injure metals which come in contact with the preservative?

Mr. Barnum: As to action of preservatives on iron and steel, creosote has no action that I know of. It does not cause deterioration in the iron cylinders or iron tanks in which it is used. Zinc chloride does; there is present in this solution a certain amount of free hydrochloric acid, and it is this that attacks the iron in the treating cylinders and tanks. The action is more severe on wrought iron than on cast iron; it will eat through a ¼-in. tank in 7 or 8 years.

Mr. Roper: Would that occur with railroad spikes?

Mr. Barnum: I have never heard what action zinc chloride solutions have in that connection. It might weaken the spike, but I do not know of any instance where this has occurred.

Mr. Chanute: If any of those present are thinking of trying to prevent the action of hydrochloric acid, I will say that the simplest thing is to keep in the storage tank a slab of zinc so as to take up every particle of free acid. We have practiced that method continually, with the result that we have on hand a venerable cylinder, which is now 20 years old,—not much good, I will admit, but still it can be used,—and our cars last from 7 to 8 years. We have had more trouble from the use of the peculiar grade of creosote which we have imported from Germany, which contains 25% of tar-acids, and which has eaten the iron more rapidly than the zinc chloride.

W. W. Curtis, M. W. S. E.: With reference to the hydrochloric acid in properly made chloride of zinc, there is no free acid. I have tested for it a number of times without having found it.

As to the action of zinc chloride on metal; I think it is due to the fact that the zinc chloride is a deliquescent salt and tends to maintain a condition of moisture in the wood, which may have some effect on spikes. But so far as the effect on the storage tanks is concerned, I think we may consider that there is none. I have used steel storage tanks with zinc chloride of 60% strength, and if the tanks are given any kind of care at all, one can figure on their lasting for 10 or 12 years. There is a deterioration of the cylinders and of the cars in plants using zinc chloride, but in my judgment it is not the result of action of any acid, but of the atmosphere, acting on a surface, which is alternately wet and dry. A cylinder is subjected perhaps three times a day to steam, then to a solution, and then to air, and there is that same condition in connection with the cars, with the consequence that they rust. To my best knowledge this action is from oxidation and not from the effects of acid.

I have been interested in listening to the paper this evening, but the author is more enthusiastic than I have ever felt it safe to be. The conditions surrounding the life of treated timber are so variable, and the life is so modified by those conditions, that it is difficult to speak positively as to results.

I used to say, years ago, when it was more difficult to convince people than it is now, that one could rest perfectly secure in the proposition that he would secure as long a life with ties made from inferior wood, treated with zinc chloride, as he would from white oak ties untreated. That statement was sufficient, in my judgment, to justify any and every railroad company in adopting treated timber, and it was a conservative statement. At this time there is not much difficulty in convincing railroad companies that it is desirable to treat timber,—particularly railroad ties. There has been a wonderful change in thought along these lines in the last few years.

The results of some of my investigations made about 12 years ago indicated that up to that time there had been treated in this country, all together, less than 10,000,000 ties. Since then, plants that I have built myself have treated nearly that many ties in one year. I have not seen the statement of statistics, but should be very much surprised if 15,000,000 ties were not treated last year in this country.

The Forest Service has been doing very good and valuable work, but I am free to confess that I think they did better service 3 to 5 years ago than they have within the last 2 years. Many problems in the treatment of timber have been solved, but there are many still unsolved. The department in past years has devoted its energy largely to attempting to solve such problems as the determination of the length of time the ties should season before treatment; the relative amounts of the salt solutions which could be injected with varying lengths of seasoning, etc., but it seems to me the Forest Service, in the last 2 years, has forgotten the purpose of its vocation, has gone outside of its sphere, and is becoming a commercial organization, rather than a scientific one as it was originally designed to be.

My attention was called, last spring, to a plant built in southern Ohio, described in a paper by one of the employes of the Forest Service, which he said was designed and built by the Forest Service. Shortly after that my attention was called to a letter received by a railroad official from an officer of the Forest Service, soliciting business for a timber-treating plant which it was announced the Forest Service had decided to build in Montana, the idea being to treat ties for the railroad company; or, if the railroad company preferred to build its own plant, the Forest Service offered to furnish plans and specifications, and all information and instruction, gratis.

There are a few engineers in this country who have attempted to develop a business along the lines of timber preservation, and it seemed to me somewhat incongruous for such men to compete with the United States Government. Finally I wrote to Secretary Wilson and called his attention to these facts. I told him that when I began my investigations 12 years ago in connection with this matter I had hoped to have something to do with the development of the business; that the Department of Agriculture was doing absolutely nothing in this line at that time, and it was some years after that before they actually took up the matter; that they had done good work in the way of reports which had been written and which contained a great deal of valuable information, but that that was some years ago. I asked him whether conditions had reached the state where professional men must compete with the government. Mr. Wilson said I was entirely right; that it was not the province of the government to compete with engineers or anyone else, and that the only reason that the department had taken up the matter was because, at the time they had done so, no one had succeeded in showing that soft-wood ties could be treated successfully so as to preserve them from decay. I then wrote Mr. Wilson that it was well known how to treat a soft-wood tie, but that what we did not know was how to properly treat a hard-wood tie. Shortly after that I received a pleasant letter from Mr. Hall, Assistant Forester, repeating the statement that the department had no desire to compete with the engineers, and that it was only in special conditions they were assisting in the construction of plants. I asked him for what reasons the proposed plant was considered desirable in Montana; also for what reasons the plant had been designed and built for southern Ohio, but the answer was not satisfactory.

My attention was called recently to a paper which had been received by one of the railroad companies in Chicago, entitled "Suggestions for Treating Railroad Ties with Wood Preservatives for Railroads in Eastern and Central States." dated June, 1909. There are some remarkable statements in the paper, and I wrote to Mr. Hall and asked whether it had received the approval of the department. His reply was to the effect that they were unable to identify the paper, and asked if I would send a copy to him. I was rather surprised that they did not recognize their own child. As yet I have not been informed that the paper has been disowned.

The report is in most respects reasonably accurate; it describes the various classes of timber that can be treated; it gives in great detail the cost of treatment and resulting life both of the untreated and the treated ties; it gives a description of the various classes of treatment, etc. Then I found something which rather surprised me. (It might be well for me to state here that I have no interest in any process of creosoting ties.) I found in that paper a description of the empty-cell process. The empty-cell process as ordinarily understood is represented by two patented methods,—the Rueping and the Lowry.

The Congress of the United States, in 1790, concluded that it was wise to adopt a patent system in this country, and some people have endeavored to show that our prosperity has been largely based upon the monopoly for a term of years, secured to inventors by that law, which has been amended several times, but never repealed.

I will read a paragraph, which I found in the "Suggestions."

> "The empty-cell processes at present most generally practiced—namely, the Rueping and the Lowry— are patented. For their use a royalty is charged,—2 cents a tie for the former and what amounts to from 6 to 9 cents for the latter. It is probable that the payment of these royalties is unnecessary. For the treatment of 750,000 annually, they would amount to $15,000 for the Rueping and at least $45,000 for the Lowry treatment. The Forest Service has had experience in devising methods of empty-cell treatment, and

> the results obtained strongly indicate the possibility of devising practical empty-cell processes which will not infringe on existing patents. For instance, two years ago a member of the service devised an empty-cell treatment for cross-arms. By the introduction of a preliminary vacuum, a small technicality, the method of treatment was made distinct from a patented process. Again, an empty-cell treatment has been worked out for treating mine timbers which is based on a non-pressure process. Briefly, in the opinion of the Forest Service, it would not be good policy for the Company to adopt a patented empty-cell process without a most careful consideration."

That is, by the way, a misstatement of fact. The 6 to 9 cents mentioned includes not only the royalty but a profit on the construction and operation of the plant. "It is probable that the payment of those royalties is unnecessary." It seems to me a little out of place for one department of the government to use the public funds to try to undermine a system established by another and superior branch of the government. I do not know whether the Forest Service will have the patent laws repealed by the next Congress or not; probably it will.

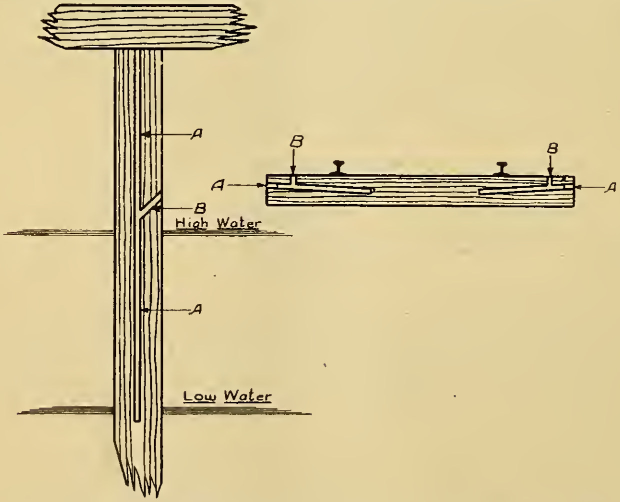
I find in this report also:

> "Ties of some porous wood, such as loblolly pine and black gum, can be treated effectively in a plant of comparatively light and inexpensive construction, equipped for the application of a low pressure (70 pounds). The Forest Service has designed such a plant for the Indianapolis, Columbus & Southern Traction Company, of Columbus, Indiana, and the Tennessee Coal, Iron and Railroad Company, of Birmingham, Alabama. A plant of the same general type but of heavier construction has been designed for the Great Southern Lumber Company, of Bogalusa, La. The capacity and estimated cost of these plants is as follows:
>
> | | Annual capacity | Maximum pressure | Estimated cost |
> |---|---|---|---|
> | (1) I. C. & S. T. Co. . . | 180,000 ties | 70 lb. | $ 6,000 |
> | (2) T. C. I. & R. R. Co. | 300,000 ties | 70 lb. | 15,000 |
> | (3) G. S. L. Co. . . . . . . | 450,000 ties | 100 lb. | 25,000 |
>
> Blue prints of plants 1 and 3 are included in this report. It is clear that a low-pressure plant is much less costly than one equipped for high-pressure. Moreover, the former type of plant is less expensive to maintain and operate and is suitable for the application of a full-cell or empty-cell treatment."

I was rather amused, in the light of Mr. Hall's letter to me of last April (in which he said that the department was not attempting to compete with private individuals), to find that 60 days later he was offering to furnish free plans and specifications for another plant; and also the services of an assistant to superintend the erection of the plant and instruct the parties in the operation thereof, for the munificent sum of $75.00 per month. I am sure that people who want that class of service are welcome to it. I think the department has gone outside of its sphere, when it undertakes to furnish plans, specifications and superintendence on such work.

Mr. Wilson, in his letter to me, suggested that he was entirely willing to stop all work in these lines whenever it was demonstrated that private interests would take it up. I replied that we did not want the Forest Service to stop its work, for there is a tremendous amount of investigation and experimental work that needs to be done in timber preservation, and which only the government has the time and money to do. Let the Forest Service do this and leave the design and construction of plants to the individual. If there were not men in this country who were familiar with the construction and operation of timber-treating plants, I would most heartily say to the Forest Service, "Go ahead!" but it is a curious fact, notwithstanding all the effort that the department has put forth, it has not yet proposed one single improvement in a timber-treating plant. It has exploited the non-pressure method, which is good for an extraordinary situation and nowhere else; but this is not a new process by any means. There has not been a single improvement made in the treating of timber which has been originally recommended by the government

Theodore Kandeler, M. W. S. E.: It has been said that the antiseptic fluid leaches out of the timber when used in wet places. Has it ever been tried to replace the preservative fluid by means of holes in the timber to contain a fresh supply?



Suppose a pile in use, as illustrated; that part of the timber between high and low water decays first. Suppose there are holes provided which will permit the replacement of the preservative (leached out) by filling these with a fresh supply. Would the capillarity in the wood transfer the preservative outwardly from the central cavity? A plug would close the opening.

Suppose a railroad tie with holes bored in from the ends, and provided with plugs which will permit the introduction of the preservative. Would that be of practical value?

Mr. Barnum: I think perhaps that would work all right. An application for a patent involving the same principle has recently been sent to the department. It is to be used in connection with treating telephone poles in position. A hole is first bored in the pole and then a small receptacle, constructed of pipe, is attached. After the pipe is in position it is filled with creosote and allowed to remain. The preservative is then gradually taken into the wood by capillary attraction. At first there were to be three openings in the pole, 120° apart, and three connections leading to the main pipe. Afterwards one was found to be sufficient. A section of a pole treated in this way was sent to the department also. It showed a good penetration of creosote, of about 1½ in. The patentees claim they can get about 12 lb. of creosote into a pole. The scheme looks as if it might be practicable, but it has not yet been thoroughly tested.

Mr. Kandeler: How far above the ground would the treating be begun?

Mr. Barnum: About a foot to eighteen inches above the ground would be sufficient. In the South the whole pole must be treated. In this part of the country I think it is only necessary to treat the butt of the pole. It is claimed that good results are secured with this treatment.

A Visitor: That estimate of 9c a pole is very attractive.

Mr. Barnum: That is only a general approximation based on the average life of all poles in this country.

Mr. Chanute: By way of explanation I will state that the idea of boring a hole in a stick of timber, in order to introduce a preservative substance, is a very old and natural one, but it was found that the results were quite unsatisfactory, in consequence of the fact that the structure of the wood is such that the sap cells chiefly communicate lengthwise with each other, so that with a given piece of timber about three-quarters of the solution goes in through the ends and about one-quarter through the medullary rays. Now, the only way in which creosote, bottled up in a hole in timber, can saturate the rest of the wood is through the medullary rays, and that has been found inefficient.

President Allen: I will ask Mr. Barnum if he can give us a description of the non-pressure process.

Mr. Barnum: The non-pressure process has received the support of the Forest Service because it is believed to supply the need of the small consumer who cannot afford to go to the expense of putting in a large plant with its complicated equipment. Several of these plants have been erected in the South for treating short-leaf and loblolly pine. The preservative is forced into the wood by atmospheric pressure. The wood is run in an ordinary cylinder, the cylinder being made of very light—¼ in.—iron, and then oil is admitted and heated up to 220 or 230 deg. F. This hot bath lasts from two to three hours and expels part of the air and moisture in the wood cells. The hot oil is then withdrawn from the cylinder and immediately replaced by cold oil. The charge of cold oil causes the expanded air to contract and a vacuum is formed which is destroyed by the entering oil forced in by the greater pressure of the atmosphere. Very good results have been secured in treating porous wood with this process, and it is comparatively easy to get the preservative all the way through loblolly and short-leaf pine—clear up to the heart. Good results have also been secured in treating red oak ties by the non-pressure process, but the red oak is more difficult to treat than pine. Of course, the non-pressure process can by no means take the place of the pressure process. It is simply advantageous for the treatment of very porous wood, where the amount of money available for the construction of a plant is comparatively small.

Mr. Chanute: I will say that if that process can inject an average of 12 lb. of solution to the cubic foot, we do not need anything better.

Mr. Curtis: In the treatment by the ordinary pressure process,one does not depend upon first heating the wood and then chilling it by the cold oil to produce the vacuum. This is done much better by a vacuum pump and then supplementing the atmospheric pressure by pump pressure. I have never got too much oil penetration in the ties, even with a 24-in. vacuum and 150 lb. pressure. I have never seen an oak tie in which I could get that degree of penetration which I think we ought to have. I do not know that I have ever treated loblolly pine ties by the full-cell process, but I have treated a great many thousand such ties by the Rueping process. With that process we first produce in the cylinder 50 lb. air pressure, and then run in the oil and put on 150 lb. of oil pressure. If the loblolly pine ties have been well seasoned, on cutting a tie in the middle it will be found treated right down to the heart, although not all the way through as a rule. It is difficult to get the solution into the heart, which, of course, will vary somewhat in size, but ordinarily it will come down to a 1½ to 2 in. ring. In other words, it was as fine a treatment as one could expect to get.

In regard to oak and some of the other hard woods, I have never been able to get uniform results. Investigation will show good treatment in one instance, while in another instance the treatment would be superficial. I do not doubt that Mr. Barnum has been able to get good results with sap-wood and loblolly pine when well seasoned. But unfortunately in the timber-treating business one wants to get uniformly good results. Of course, absolutely uniform results cannot be obtained by any process, but we are aiming to reduce the percentage of poor results. I remember that Mr. Chanute became discouraged at one time with tamarack wood because he could not get absolutely uniform results. I am in some doubt as to the results which we are going to find in this country 10 years from now, with the oak ties we are treating with oil today. Some of the results which have been secured in oak, in this country, with the zinc chloride process, have been remarkably good, and some much better than I was ever sanguine enough to anticipate. I think the first year that the Carbondale plant was run it treated a lot of red-oak ties for southern Illinois, where the rainfall was about sixty inches, and the last report I had was that those ties showed up remarkably well. However, I should never anticipate very great results from red-oak ties laid in that territory. There is a good deal of clay there, which is a great water holder. The rainfall, too, is very heavy.

The results from treating timber with zinc chloride have been remarkably satisfactory.

I believe that there are many things to be learned about timber, and about treating it, and I am hoping that Mr. Barnum will teach us how to secure those uniformly good results that we are all looking for. I have tested a great many sticks and have been surprised and disgusted by the failure to get results. This summer it was necessary to treat a lot of long-leaf yellow pine soon after it was sawed. It was given a much longer treatment and more steaming than usual. The steaming was continued for six hours at a reasonably high pressure—the oil pressure was 165 lb. The work was done in a plant where I know the treatment was absolutely conscientious, yet on sawing some of those sticks in the middle, the results were very disappointing. I reached the conclusion that if I had any more timber to treat fresh-sawed, it must be loblolly pine, as long-leaf pine is not fit to be so treated. The vast difference between the penetrability of timber to a water solution and to oil is a curious thing.

Mr. Barnum: The Pennsylvania Railroad Co. has recently built a new plant, where they are treating red-oak wood and are getting a thorough penetration. The ordinary oil pressure treatment is given, after which an air pressure of 100 lb. per sq. in. is placed on the timber. This air pressure is held for about half an hour. When the air pressure is released a vacuum is drawn and held for the same period. The air pressure and vacuum diffuse the oil entirely through the wood in a uniform manner.

President Allen: I recently saw some samples of timber treated by a process applying a pressure at one end of the stick, with a vacuum at the other end. Can anyone tell us about that process?

Mr. Curtis: It is only a modification of the old Boucherie process. There are other methods similar to that you mention, excepting in minor details. There is no virtue in the vacuum; it exists only through absence of pressure, and an increase of pressure at the other end amounts to the same thing.

L. J. Hotchkiss, M. W. S. E.: I should like to ask if Douglas fir takes treatment satisfactorily. We are using a great deal of this timber and I have been told that it cannot be successfully treated. If anyone here has tried to do it, I wish he would tell us what his experience has been.

I should also like to ask as to the relative merits of treating timber which has been air-seasoned, and of taking it green and steaming it as a part of the treating process. Not long ago I was talking with a man who is in the business of treating timber, and he advocated steaming it. His idea is that the life of a stick of timber is only a certain number of years and if it is air-seasoned before treating, the time required for this seasoning is just so much of its useful life lost. He thinks if it is steamed instead, this loss is avoided with no injury to the timber to offset it. I should like to know the opinion of others on this point.

Mr. Chanute: In regard to Mr. Hotchkiss' second inquiry, with reference to steaming. We have tried several hundred experiments in order to determine the advantage or disadvantage of steaming, and found that, in order to extract the sap, it was necessary to have some motive power. If the wood was partly seasoned the sap has evaporated to a good degree and air has flown into the sap cells. Now, by steaming, the air is heated and drives the sap out of the cells. If the timber is fresh cut and full of sap you have got to apply sufficient heat to the center of the tie to generate steam—or a heat of 212 deg.—in order to drive out the sap and replace the action of the heated air. We took ties and steamed them one, three, five, six, seven, and twelve hours. We bored holes in them, which we plugged up, and after the tie came out we removed the plug and inserted a thermometer, to ascertain what the temperature was. We found we got a temperature of 212 deg. F. with not less than 8 hours steaming.

In creosoting piles in the South, I understand in some cases they are steamed 24 hours before the sap can be extracted and the creosote put in.

With respect to the first question asked by Mr. Hotchkiss, as to whether Douglas fir takes treatment satisfactorily or not, I may say that the Southern Pacific R. R. Co. claim they treat it better when it is fresh cut than after it is seasoned, and all the ties which they are treating are treated fresh cut. I thought the statement extraordinary, and went out to California to investigate the matter. I found that the information was correct,—that the Douglas fir, fresh cut, was more easily treated (by steaming) than when seasoned, the reason being that the Douglas fir contains a good deal of resin. That resin is fluid when the wood is fresh cut, but after the wood has been cut for a while the resin gums in the cells and resists the injection of the solution.

Mr. Curtis: I simply want to supplement what Mr. Chanute has said. If Mr. Hotchkiss refers to the treatment of timber with oil, the proposition is somewhat different. I have never had an opportunity to treat Douglas fir, but believe it cannot be done by the ordinary pressure method. The only way I know of to treat Douglas fir timber satisfactorily with oil is by boiling it in the oil and supplementing by pressure. In that way a penetration is obtained which is satisfactory.

C. F. Loweth, M. W. S. E.: Referring to Mr. Hotchkiss' question about the treating of Douglas fir, I will say that about a year or so ago we contracted with a reputable and experienced wood-treating plant to treat a lot of Douglas fir timber. The company assured us that although they had not beeen treating Douglas fir, they were confident they knew how to do it. They made an energetic, and I believe an honest effort, but the result was a failure. The timbers to be treated were the ordinary pilebridge stringers, 8x16 in. in section by 32 ft. in length; they had been lying in a yard for a couple of years or more and were thoroughly seasoned. Notwithstanding the efforts of the firm to treat this timber, it appeared impossible to force the creosote in at the sides and rarely was the penetration as much as ⅛ in. in depth; but it was quite easy to force the creosote into the ends of the timbers, and in some cases at a distance of 8 ft. from the ends, as I remember it, about half of the section of the timber would be saturated and doubtless the penetration from the ends extended a very considerable distance. This left the skin or surface, of the stick with a very imperfect and inadequate protection, because a very slight season-check would open up a portion of the interior which had received no treatment. The people made many efforts, experimenting one way and then another, and in several cases the timbers were very badly distorted by the unequal heating, etc. I am inclined to think that fir timber can best be treated while green and by what is known as the boiling treatment.

Those same people at that time had another unexpected experience. Their order included some 8x8 in. 12 ft. long Minnesota white pine bridge ties. White pine is very rare nowadays, at least for such purposes. It was generally supposed that this material would take treatment as easily as loblolly pine; but this was soon discovered to be a mistake, for the ties did not take the treatment, and what was more surprising, the contractors were not able to find out how to get the creosote into the timber. The best that could be done seemed little better than what might have been obtained by merely soaking the timber in a bath of creosote. I turned some of the samples over to Mr. Curtis who took them to one of his treating-plants and tried his method or methods, but I dare not mention the results. The white pine ties were freshly cut and full of sap and frost.

Mr. Curtis: Mr. Loweth sent to me, at my request, four samples 8 in. by 8 in., 6 ft. long, as pretty samples of white pine as I have ever seen. I expected to fill them so full of oil that they would be dripping for six months. I put one piece in the cylinder with a run of piling, and after taking it out and cutting it I was ashamed to show it to Mr. Loweth. I tried another sample by the Rueping process, and curiously enough (though we did not have the same oil pressure by 50 lb. as we did on the first trial) on that sample we got a good treatment. Other tests by the same method, however, were unsatisfactory.

When one gets into the subject of timber, no matter how expert he may be he is going to have some surprises. I would not have believed that I could have any difficulty in treating white pine. I believe that it can be done, but I will admit that I do not now know how.

Mr. Barnum: The Forest Service is anxious to work in co-operation with engineers and hopes to be of use to them in helping solve those problems which have to do with the nature and uses of timber.

LOW TENSION FEEDER SYSTEMS FOR STREET RAILWAYS.

R. H. Rice, M. W. S. E.

Presented at a Joint Meeting W. S. E. and A. I. E. E., December 22, 1909.

An electrical distribution system in general is made up of a network of conductors which convey the electrical energy from its points of generation to the locations at which it is to be utilized. The distributing lines for a street railway system constitute a special and relatively simple case of such a network. Its component parts are:

1. The contact conductor, or trolley wire, from which the car receives its current.
2. The conductors, or feeders, from the power house or substation switchboard which deliver current to the trolley wire.
3. The returns, or conductors, which complete the electrical circuit from the car to the power station.

It is the purpose of this paper to explain the methods used in calculating the feeders and to show the general results obtained on the street railway systems of Chicago, which come under the jurisdiction of the Board of Supervising Engineers.

There are four companies with 687 miles of single track operated, and a total of fifteen power stations, aggregating 95,150 kw. rated capacity. The calculations for feeders were made upon a basis of 2,264 double truck cars, or their equivalent, which were required to operate the proposed schedule.

On the lines of these companies but two steam power houses are in operation. In all other cases power is purchased and is transmitted at 9,000 volts, three phase, to the various substations and there transformed to direct current. All of these substations have been very recently built and are of the most approved construction throughout. At present the direct current bus voltage is run somewhat lower than 600 volts, but it is intended to raise it to this value, after low voltage motors have been eliminated and other necessary changes have been made.

The trolley wire on all streets is sectionalized by inserting section insulators at various points, and each of these trolley sections has a feeder consisting of one or more cables extending from the section to the power station most convenient to it. The choice of locations for these section insulators is largely dependent upon operating conditions, and also upon the location of a section with reference to the power station.

To determine the actual power requirements for the type of double truck car now used in Chicago, a series of fifteen tests were made on a car which was operated in regular service for three days. This car was equipped with ammeters, voltmeters, a recording watt-hour meter, and a speed recorder. A careful log was kept of its operation under all the varying conditions of service on different lines and at different periods of the day.

In addition to the above individual car tests, several section tests were undertaken. These consisted in determining the number of cars on a chosen trolley section by observing the times of entrance and exit of cars from the section and during the period of the test, noting the ammeter and voltmeter readings at the station switchboard. The chosen sections were of several miles in length and the traffic over them was quite heavy. All tests were run between 12 m. and 8 p. m. From the results of these tests the power requirements for a car under various conditions were determined and used in the feeder calculations.

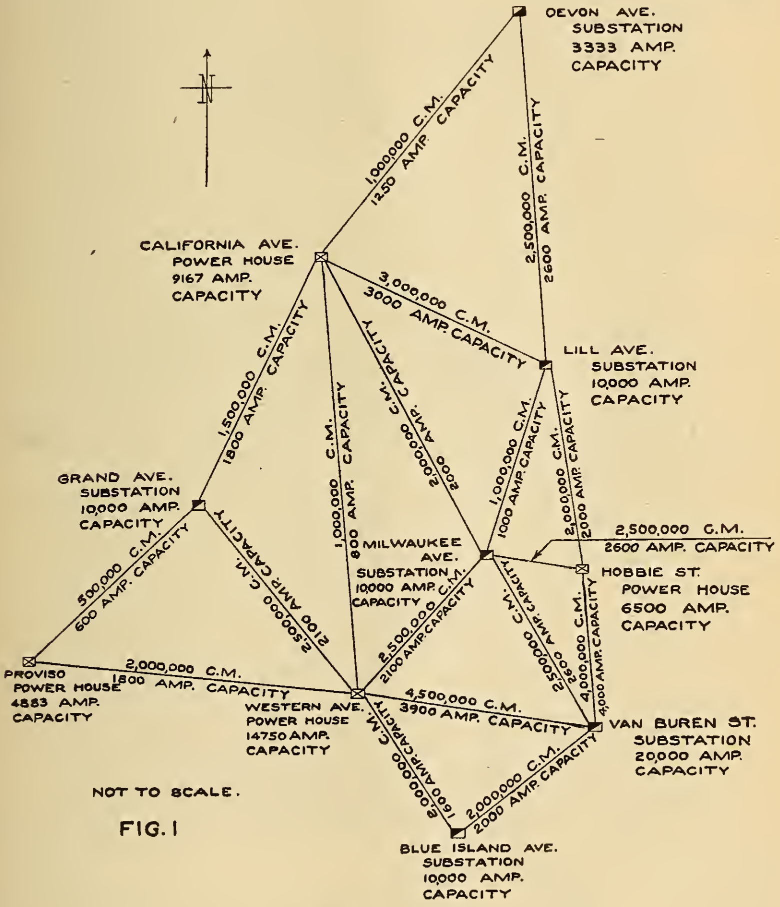
Some study was also given to the safe carrying capacity of cables, and as a large portion of the territory covered by the feeder system is designated as underground territory by the ordinances under which the railway companies are operating, it was necessary to consider lead sheathed, as well as weather-proof overhead cables. Owing to the presence of various tunnels, low subways under railroad tracks, and some low level duct lines, it was considered desirable to use rubber insulated cables in these places and paper insulated cables elsewhere.

A question of considerable importance is the interconnection of stations so that the temporary shutdown of one will not throw out of service all the sections fed from that station. One method of accomplishing this, would be to install into every station sufficient copper leading from the adjacent stations to enable the full-current capacity of the disabled station to be fed into it from the others. The presence of such trunk tie lines would be highly desirable during an emergency, but would be of no service at other times, except as equalizers between the stations. The investment necessary for such ties would be quite large, and essentially the same results may be secured by selecting a certain number of the more important trolley sections and feeding them from two stations. The feeders to these sections are so proportioned and calculated, that on the whole system in case of the shut-down of one or two stations, a certain proportion of the cars can be carried on the remaining stations by interconnecting through these tie lines.

On any individual trolley section, in case of the shut-down of one station, or of accident to one feeder, the cars on the section could still be operated from the other station by means of the second feeder.

The illustration, Fig. 1, shows the station capacity of one system in amperes, for operation at 600 volts. Local conditions and the situation of the stations determine the tie capacity between any two of them. In the system here shown the stations are very completely tied together and each has a tie capacity into it, which is a large percentage of its output.

In any street railway system the load will fluctuate widely, and it is a question of importance to determine upon what particular basis to design the feeder system. The load factor, that is, the ratio of the average load during any period of time to the maximum within the period, is practically 50% for a twenty-four hour period on the systems under consideration. The curves of Fig. 2 are typical for a twelve-hour period. The other twelve hours give practically duplicate curves.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LILL AVE. SUBSTATION 10,000 AMP. CAPACITY
1,500,000 C.M. 1800 AMP. CAPACITY
1,000,000 C.M. 800 AMP. CAPACITY
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GRAND AVE. SUBSTATION 10,000 AMP. CAPACITY
500,000 C.M. 600 AMP. CAPACITY
2,500,000 C.M. 2100 AMP. CAPACITY
MILWAUKEE AVE. SUBSTATION 10,000 AMP. CAPACITY
2,500,000 C.M. 2100 AMP. CAPACITY
HOBBIE ST. POWER HOUSE 6500 AMP. CAPACITY
2,500,000 C.M. 2600 AMP. CAPACITY
4,000,000 C.M. 4,000 AMP. CAPACITY
PROVISO POWER HOUSE 4883 AMP. CAPACITY
2,000,000 C.M. 1800 AMP. CAPACITY
WESTERN AVE. POWER HOUSE 14750 AMP. CAPACITY
4,500,000 C.M. 3900 AMP. CAPACITY
VAN BUREN ST. SUBSTATION 20,000 AMP. CAPACITY
2,000,000 C.M. 1600 AMP. CAPACITY
2,000,000 C.M. 2000 AMP. CAPACITY
BLUE ISLAND AVE. SUBSTATION 10,000 AMP. CAPACITY
NOT TO SCALE.

FIG. 1

The average maximum curves *C* and *D* represent the average of maximum daily values for the selected months. The average curves for the various number of hours, such as *E* and *F*, represent the steady load which would be equivalent in kilowatt hours to the actual load as it exists on the station for the twelve-hour period shown.

If the feeder system is designed to carry the peak loads, such

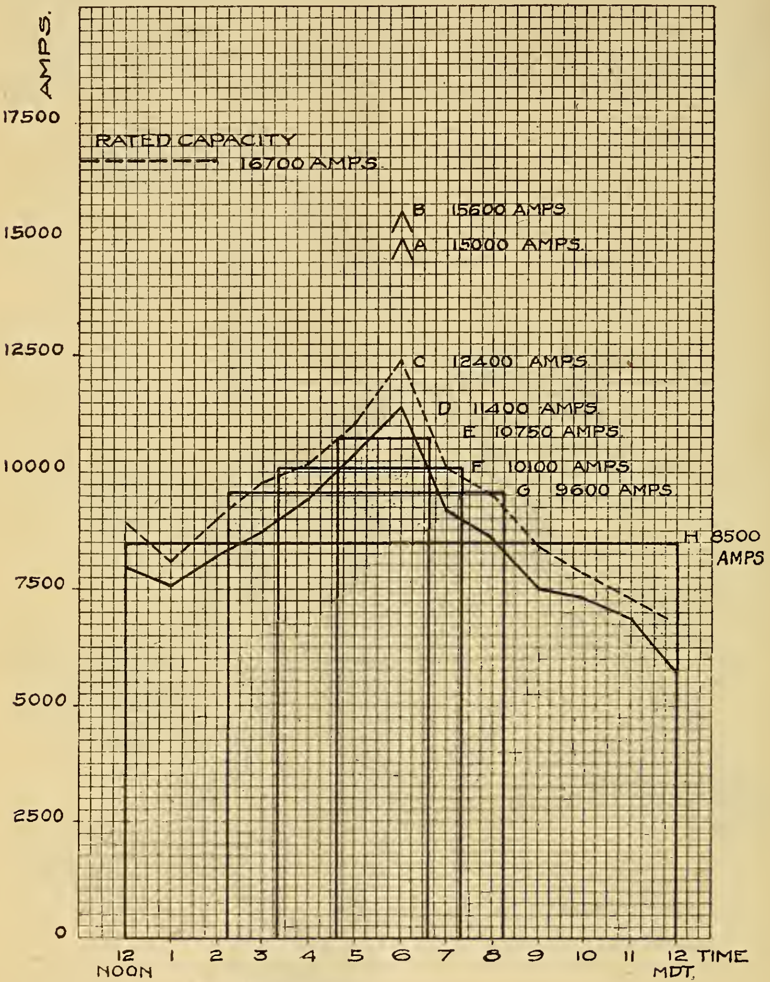


FIG. 2

A: DEC. '07 MAX.
B: JAN. '08 MAX.
C: JAN. '08 AVE. MAX.
D: 3 MONTHS AVE. MAX.
E: 2 HOUR AVERAGE
F: 4 HOUR AVERAGE
G: 6 HOUR AVERAGE
H: 12 HOUR AVERAGE

as *A* and *B*, without an overload on the cables, then during a large part of the day the current in the cables will be far below their safe carrying capacity and considerable copper will be idle. On the other hand, if the feeder system should be designed on a basis of say a six-hour average, as shown by curve *G*, then the cables would be subjected to large overloads for a considerable period of time, heating would occur, the cables would more rapidly deteriorate, and a shorter life would result.

It was decided to use the two-hour average as a basis for all calculations, in this case represented by curve *E*. This means that the feeder systems are so designed that they will carry the entire load without being overloaded, except during a two-hour morning and evening peak. The ordinary percentage of excess load is well within the overload capacity of the cable—that is, the current it will carry for this short period without undue heating.

From the preliminary studies and tests made by the Board of Supervising Engineers, as previously outlined, the basis for all feeder calculations was formulated and established by resolution. This basis may be itemized as follows:

1st.—The direct-current bus bar at power houses or sub-stations will be operated at approximately 600 volts.

2d.—An allowance of 40 kw. in power house or sub-station capacity for each standard double-truck car of the type approved by the Board of Supervising Engineers, weighing approximately 26 tons, light, or its equivalent, will be provided at each direct-current bus bar.

3d.—In calculating the copper for current-carrying capacity an allowance of 75 amperes for each standard double-truck car, as described above, or its equivalent, shall be allowed.

4th.—An average drop of 50 volts will be allowed between the D. C. bus bars and the center of gravity of the trolley section, due provision being made for suitable tie lines to take care of emergency cases.

5th.—The carrying capacity in amperes of insulated lead-covered underground cables and of overhead weatherproof cables shall be calculated upon the following basis:

	Lead Covered		Triple Braided
	Rubber	Paper	Weatherproof
1,000,000 C.M. Cable	800	1000	1250
500,000 " "	500	600	625
350,000 " "	375	425	450
4/0 " "	...	...	325

The general method adopted in feeder calculations may be illustrated by the successive steps used in one particular system, the detail of calculation being shown later.

1. From the proposed schedules, the number of cars which

will be operated on each route during the rush hours is determined. The cars are distributed and plotted upon a skeleton map of the system which is called a *Spot Map* or car distribution map; Fig. 3. The afternoon maximum period is usually the heaviest service period, so that the car distribution for two hours of what is styled the *P. M. Rush* is used on this map.

2. The trolley sections, as previously determined, are then drawn, and the number of cars on each are multiplied by 75, which gives the total average maximum load for each individual trolley section in amperes. This amount is placed in a small circle at the center of gravity of the trolley section, and the map is known as the trolley section or load distribution map, as shown in Fig. 4.

3. A study is then made of the proper location of power stations. The best probable locations are selected, and a calculation of station load centers is made by finding the combined center of gravity of the loads about a given station, as indicated in Fig. 5. This center of gravity of the loads is determined by the well-known process in mechanics, in this case the number of amperes on each section taking the place of the number of pounds weight. In the case of tie sections, the load is divided between two stations in amounts which may readily be calculated, as shown later. The section is thus virtually divided into two sub-sections of such lengths that the load on one sub-section is carried by one station and the load on the other is carried by the second station. The dotted circles represent the centers of load of these sub-sections, and the numbers within them the portion of the total load on the sub-section.

If a given system is to be fed by a single power house, the system load center is also determined, which will show the most economical location, so far as distribution copper is concerned, for the generating station. If the locations chosen are not the most economical for distribution copper, studies are made of comparative costs for other locations where the company may have property or where real estate for sub-station purposes may be obtained to advantage.

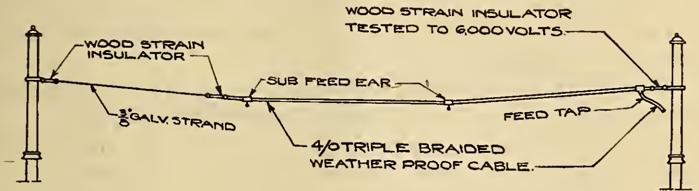
4. After the station locations are definitely settled, and the sections which are to be fed from each station are decided upon, a *Spider Diagram* is added to the trolley section map, which now becomes a drawing of record and shows at a glance what sections are fed from any given station, and what average maximum load is to be expected upon that section. This is illustrated in Fig. 4.

5. A study is then made of the feeder routes, and having determined them, a *Feeder Diagram* is prepared which shows the route and number of each cable from the power station to the section load center, as shown in Fig. 6.

6. If the feeders are to be placed underground, it is neces-

sary to lay out conduit lines. A diagram, Fig. 7, is used for this, the number of cables over a given section being represented arbitrarily by the numerator of a fraction, and the number of ducts by the denominator. Extra ducts are provided in all conduit lines where practicable, to provide for future growth without tearing up pavements. The percentage of extra ducts will vary for different locations, depending upon the estimates of future requirements.

A typical feeder tap is illustrated in Fig. 8, which shows the lead-covered cable rising up the pole and passing into the switch box. From this point weatherproof cable is used, passing upward and being connected to the feeder span which replaces the galvanized strand wire used on other spans. An overhead feeder tap is also shown on the same drawing.


WOOD STRAIN INSULATOR TESTED TO 6,000 VOLTS.
WOOD STRAIN INSULATOR
SUB FEED EAR
$\frac{3}{8}$" GALV. STRAND
FEED TAP
4/0 TRIPLE BRAIDED WEATHER PROOF CABLE.

TYPICAL FEED SPAN CONSTRUCTION.

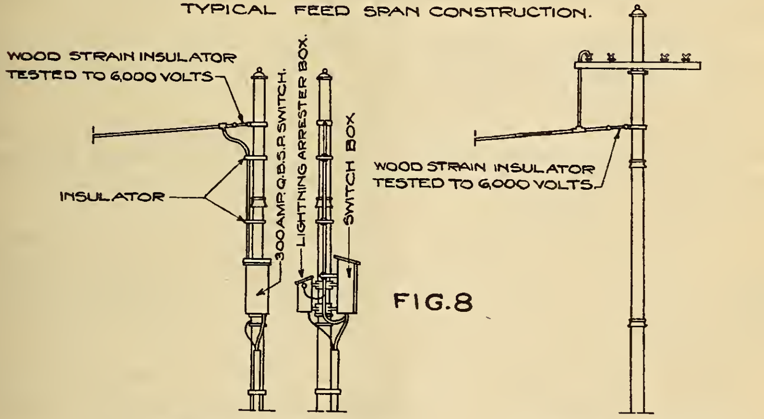

WOOD STRAIN INSULATOR TESTED TO 6,000 VOLTS
INSULATOR
300 AMP. Q.B.S.P. SWITCH.
LIGHTNING ARRESTER BOX.
SWITCH BOX
WOOD STRAIN INSULATOR TESTED TO 6,000 VOLTS.

FIG.8

TYPICAL UNDERGROUND FEEDER TAP

TYPICAL OVERHEAD FEEDER TAP

The calculation of feeders may be conveniently based upon two theorems in addition to Ohm's law:

1. The maximum drop, measured from one end of a uniformly loaded conductor, is one-half the drop produced by an equal load concentrated at the distant end. Or stated in another way, the maximum drop on a uniformly loaded conductor is equal to the drop produced by the total load concentrated at the center of the conductor.

2. This theorem has to do with the mathematical similarity

between moments in a mechanical system and drops in an electrical system. For example, a beam supported at both ends and having on it a certain distribution of load will be in equilibrium when the sum of the moments about any point on the beam is zero. Similarly, if a conductor has current fed into it from both ends to supply any distribution of load upon it, there will be for every distribution some point of division on the conductor through which no current flows. This is the point of maximum drop, and of equal drops from both ends, and the system may then be said to be in equilibrium. In the electrical system we have current, resistance, and drop, corresponding respectively with load, distance, and moment of the mechanical system. If the conductor is of uniform size, we may use length of conductor instead of resistance.

In making the detailed calculations for the various trolley sections, two types of sections are to be distinguished:

A. *Isolated;* those receiving power from one station only.

B. *Tie;* those receiving power from two stations.

The fundamental assumptions underlying all these calculations are:

1. All stations operating at the same voltage. If this is not the case, a simple modification may be made in the calculation to properly provide for the difference.

2. The load on each trolley section is uniformly distributed, and feeder taps at approximately equal intervals reduce the load uniformly. This is a condition which is approximately true in city systems operating on a short headway.

3. No account is taken of the conductivity of the trolley wires which are in parallel with the feeder for a portion of its length. In any ordinary case, the trolley wires form such a small part of the total copper required for a section that their neglect introduces small variation in the results of calculation.

Most, or perhaps all, of the above assumptions would be modified in calculations involving an interurban road or a small city system.

In the case of an isolated section, such as shown in M, Fig. 10, the calculation is very simple. The section $A\ B$ of length L feet has a uniformly distributed load of I amperes, which is considered concentrated at the center of the section. If r is the resistance per foot of feeder, the drop from the power station to the nearer end of the section is $r\ D\ I$. The added drop to the end of the section is $\frac{1}{2}\ r\ L\ I$, if the feeder is continued undiminished in size to the end of the section. The total drop is as given by the equation $E=r\left(D+\frac{L}{2}\right)I$. (1) If the feeder is reduced in size as the load decreases, the maximum drop at the end of the section will be somewhat greater than that given.

Western Society of Engineers
XV—3. June, 1910.
Low Tension Feeder Systems for
Street Railways.
R. H. Rice.

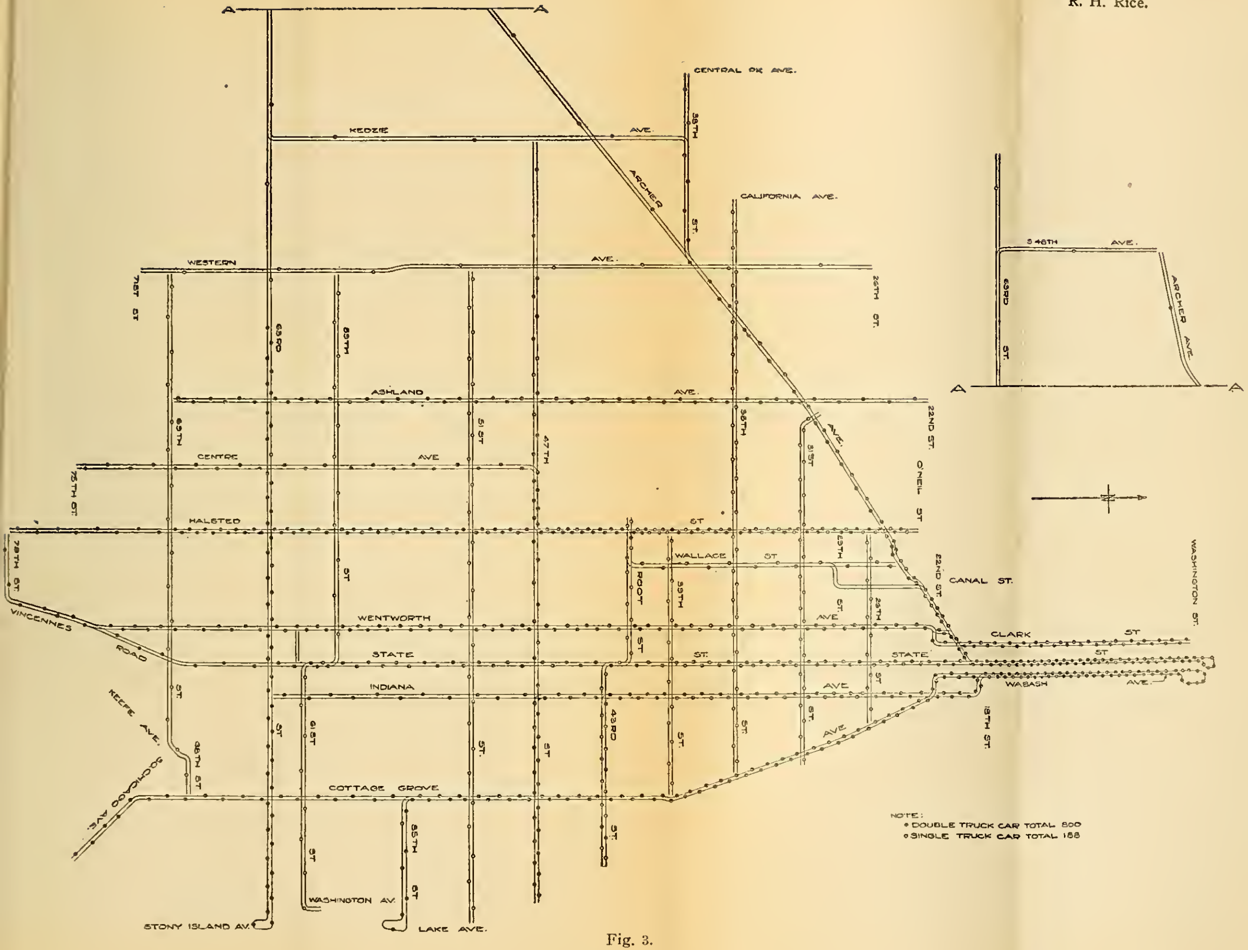


Fig. 3.

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Low Tension Feeder Systems for
Street Railways.
R. H. Rice.

SUB-STATION	LOCATION
PLYMOUTH PL.	PLYMOUTH PL. NORTH OF HARRISON ST
NO.1	20TH ST AND DEARBORN ST.
NO.2	42ND ST AND WABASH AVE.
NO.3	WENTWORTH AVE SOUTH OF 63RD ST.
NO.4	48TH ST AND HONORE ST.

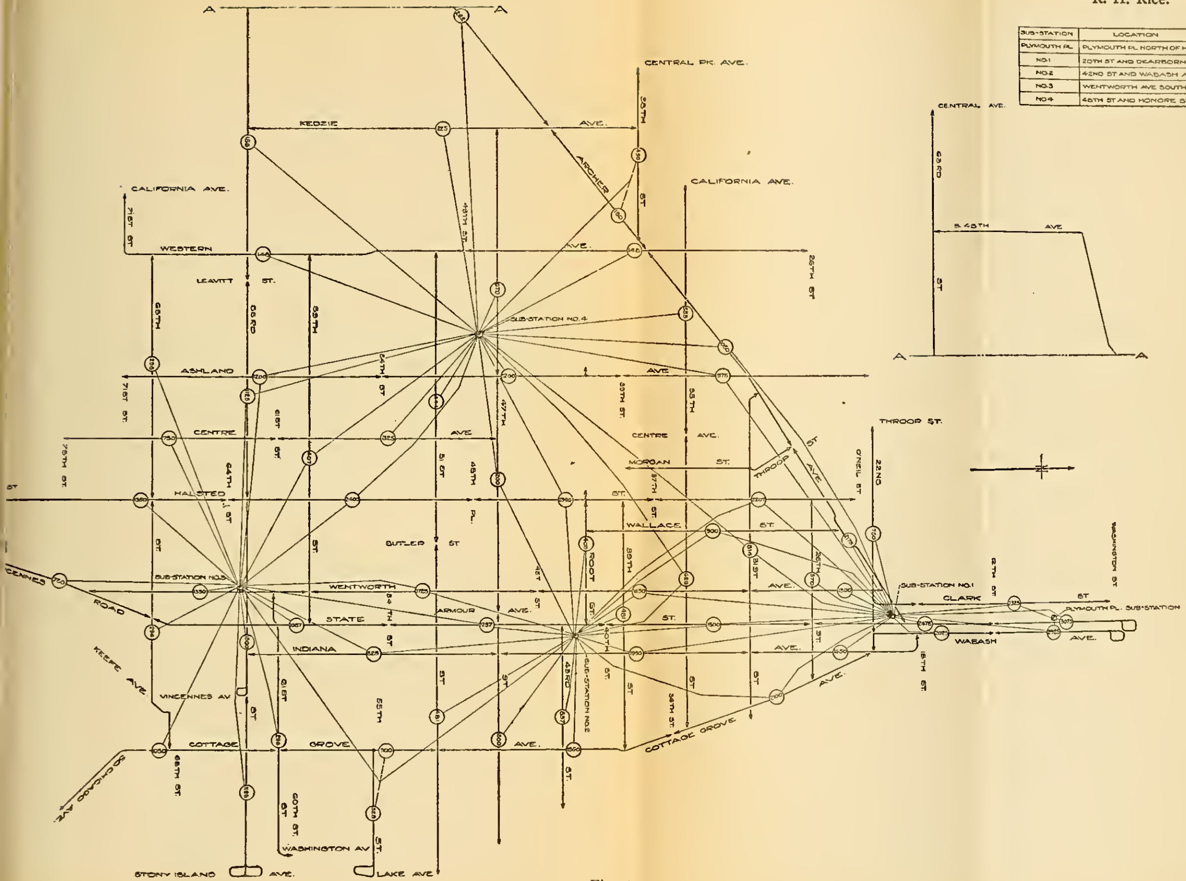

Fig. 4.

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Low Tension Feeder Systems for Street Railways.

R. H. Rice.

SUB-STATION	LOCATION
PLYMOUTH	PLYMOUTH PL. NORTH OF HARRISON ST
NO.1	20TH ST AND DEARBORN ST
NO.2	42ND ST AND WABASH AVE
NO.3	WENTWORTH AVE SOUTH OF 63RD ST
NO.4	48TH ST AND HONORE ST

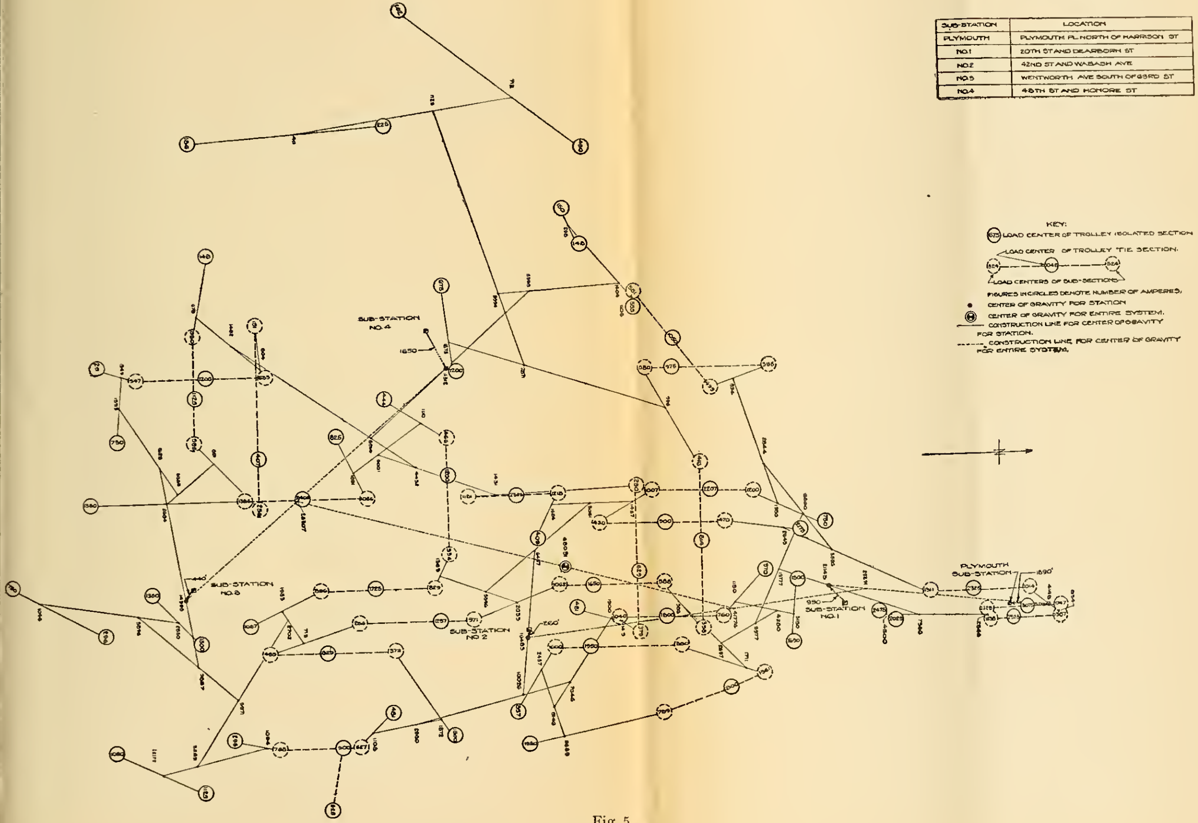
SUB-STATION NO.4
1650
SUB-STATION NO.3
440'
SUB-STATION NO 2
260'
PLYMOUTH SUB-STATION
1890'
SUB-STATION NO.1
950
KEY:
675 LOAD CENTER OF TROLLEY ISOLATED SECTION
LOAD CENTER OF TROLLEY TIE SECTION.
524
1048
524
LOAD CENTERS OF SUB-SECTIONS
FIGURES INCIRCLES DENOTE NUMBER OF AMPERES.
CENTER OF GRAVITY FOR STATION
CENTER OF GRAVITY FOR ENTIRE SYSTEM.
CONSTRUCTION LINE FOR CENTER OF GRAVITY FOR STATION.
CONSTRUCTION LINE FOR CENTER OF GRAVITY FOR ENTIRE SYSTEM.

Fig 5.

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Low Tension Feeder Systems for
Street Railways.
R. H. Rice.

SUB-STATION	LOCATION
PLYMOUTH	PLYMOUTH PL. NORTH OF HARRISON ST
NO.1	20TH ST AND DEARBORN ST.
NO.2	42ND ST AND WABASH AVE.
NO.3	WENTWORTH AVE. SOUTH OF 63RD ST
NO.4	48TH ST AND HONORE ST.

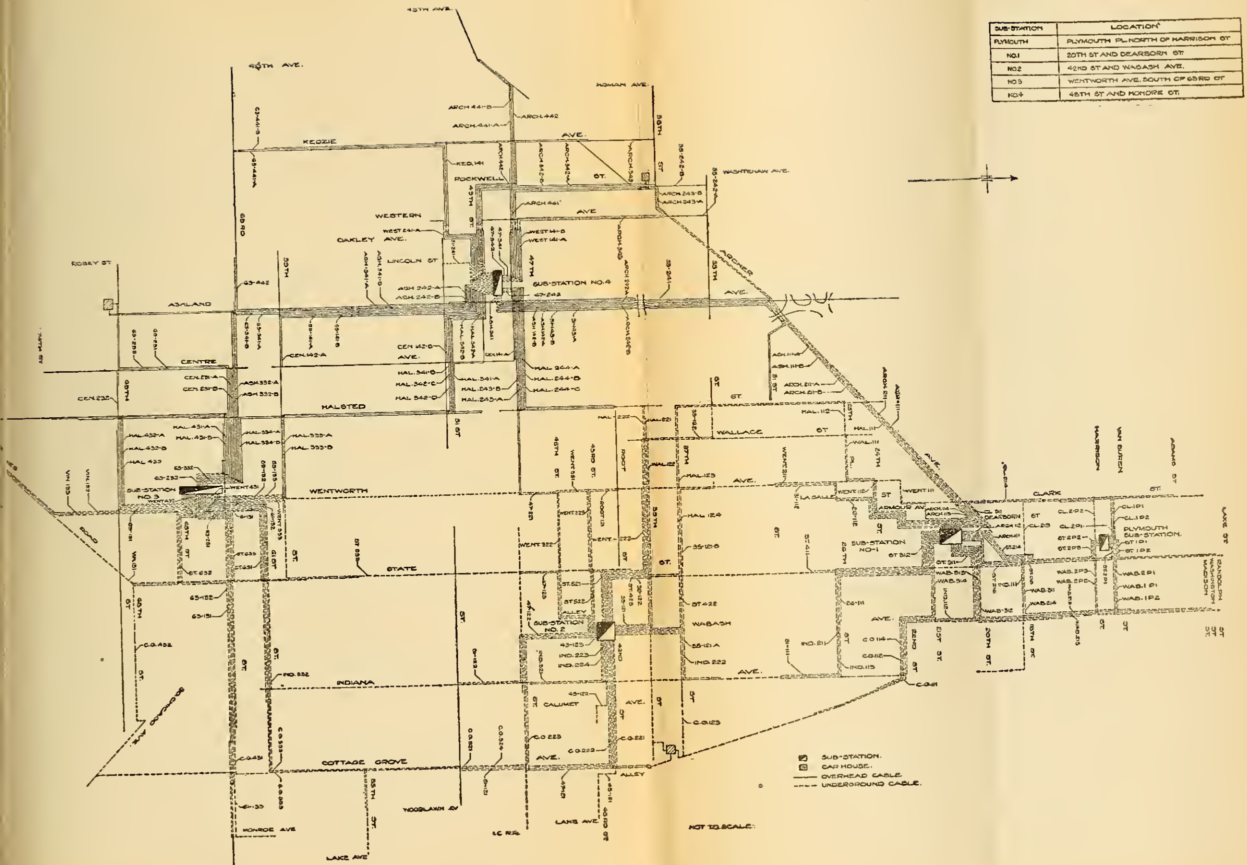

Fig. 6.

Western Society of Engineers
XV—3. June, 1910.

Low Tension Feeder Systems for
Street Railways.
R. H. Rice.

SUB-STATION	LOCATION
PLYMOUTH	PLYMOUTH PL. NORTH OF HARRISON ST.
NO. 1	20TH ST. AND DEARBORN ST.
NO. 2	42ND ST. AND WABASH AVE.
NO. 3	WENTWORTH AVE. SOUTH OF 63RD ST.
NO. 4	46TH AND HONORE STS.

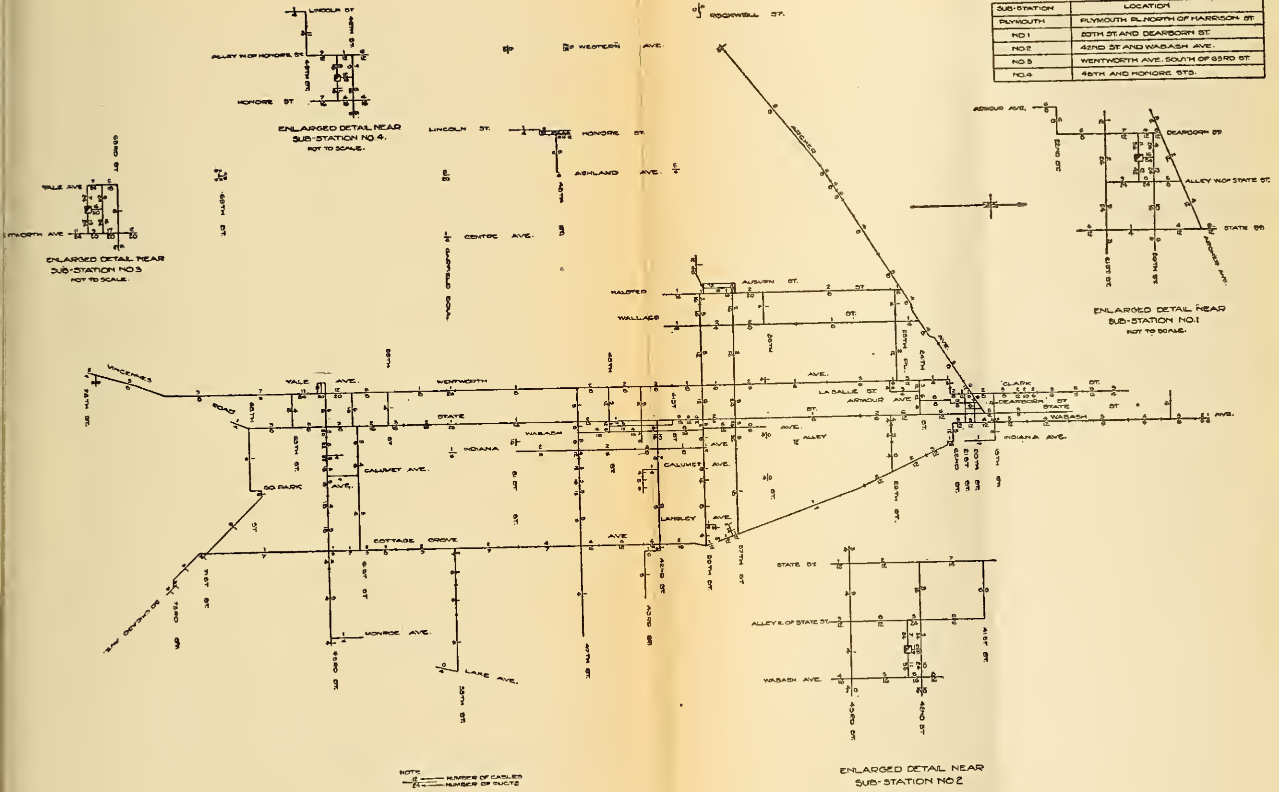

Fig. 7.

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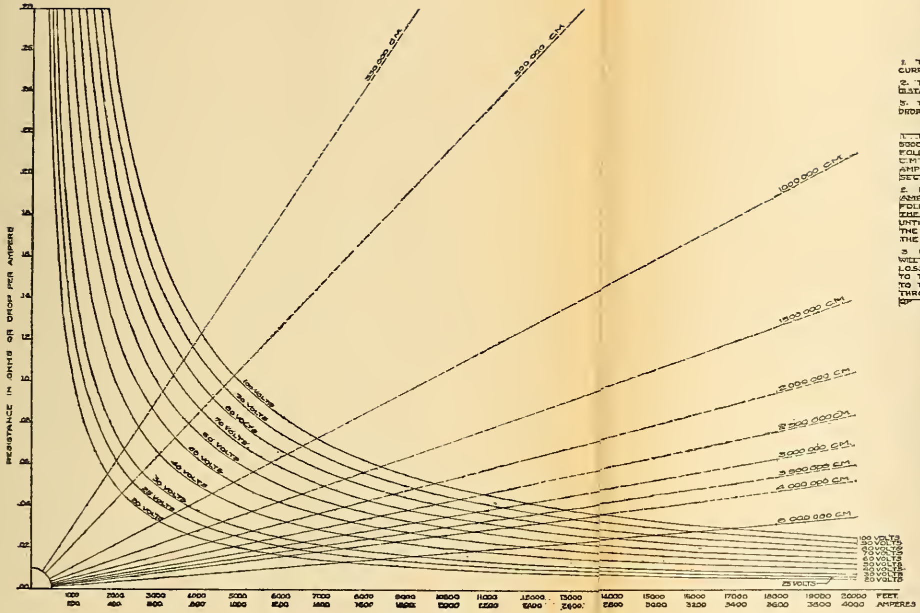
Low Tension Feeder Systems for Street Railways.
R. H. Rice.



USE OF CURVES

1. TO FIND THE DROP WHEN THE DISTANCE, CURRENT AND CIRCULAR MILS ARE GIVEN.

2. TO FIND THE CIRCULAR MILS WHEN THE DISTANCE CURRENT AND DROP ARE GIVEN.

3. TO FIND THE DISTANCE WHEN THE CURRENT, DROP AND CIRCULAR MILS ARE GIVEN.

EXAMPLES

1. FIND THE DROP ON A 500,000 C M CABLE 5000 FEET LONG AND CARRYING 450 AMPERES. FOLLOW 5000 FOOT ORDINATE UP TO 500,000 C.M. LINE. THEN HORIZONTALLY UNTIL 450 AMPERE ORDINATE IS CROSSED. THIS INTERSECTION AT 47.5 GIVES THE VOLTS DROP

2. FIND THE CIRCULAR MILS TO CARRY 800 AMPERES 8000 FEET WITH 30 VOLTS LOSS. FOLLOW THE 800 AMPERE ORDINATE UP TO THE 30 VOLT LINE THEN HORIZONTALLY UNTIL THE 8000 FOOT ORDINATE IS CROSSED THE LOCATION OF THIS INTERSECTION GIVES THE "SIZE" AS 2,250,000 CIRCULAR MILS.

3 FIND THE DISTANCE A 1,500,000 C. M. CABLE WILL CARRY 600 AMPERES WITH A 40 VOLT LOSS. FOLLOW THE 600 AMPERE ORDINATE TO THE 40 VOLT CURVE THEN HORIZONTALLY TO THE 1,500 000 C.M. LINE. THE ORDINATE THROUGH THIS LINE GIVES THE DISTANCE OF 9350 FEET.

C.M.	RES PER 1000 FEET
350 000	.030204
500 000	.021152
1000 000	.010560
1500 000	007041
2000 000	005280
2500 000	004224
3000 000	003520
3500 000	003017
4000 000	002640
6000 000	001760

BASIS: RES OF 1000 FT OF 1000,000 C M = 01056 OHMS (98.% COPPER)

NOTE: SOLID PORTIONS OF RADIAL LINES INDICATE RANGE OF CURRENT CAPACITY

Fig. 9.

The calculation of a tie section is a little more complex. Take, for instance, the simplest case, illustrated by *N* in Fig. 10, in which the main feeder between stations is assumed to extend the entire length of the section and to be uniform in size. The section *A B* has a uniformly distributed load of total value *I* mperes, of which I_1 amperes are assumed to come from station S_1 and I_2 amperes from S_2. *P* is the point of division of load between the stations, and is the point of maximum drop on the section. We are usually concerned in knowing the load on each station and the maximum drop on the section.

TYPICAL TROLLEY SECTIONS

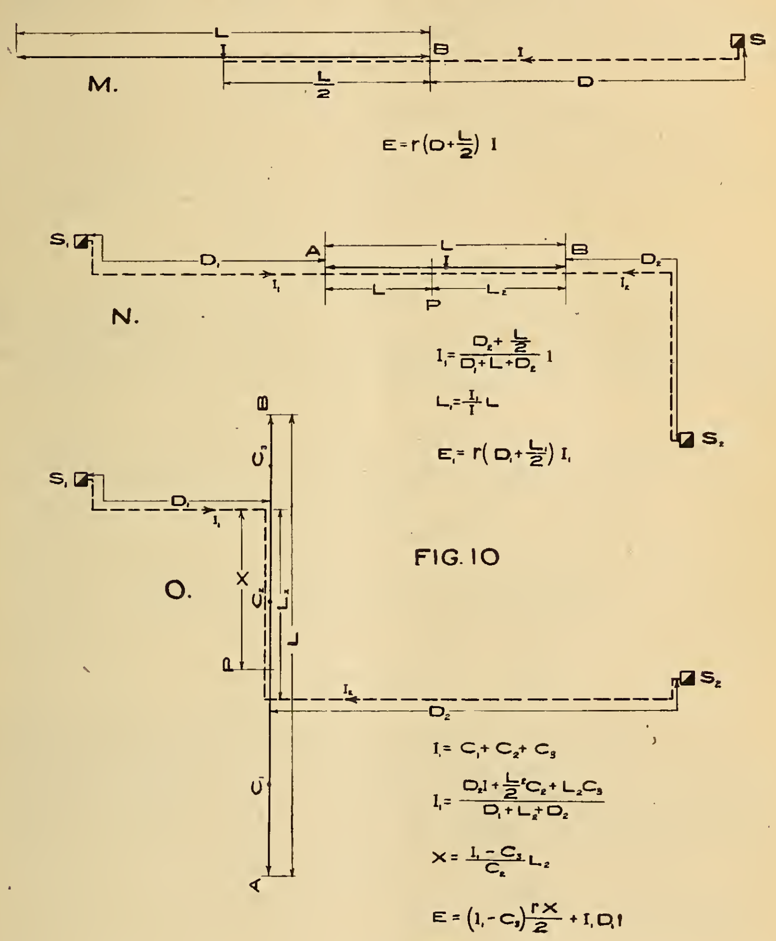


FIG. 10

To determine the load I_1 on station S_1, take moments about

S_2. These moments must be so chosen that they will involve only the one unknown whose value is sought, otherwise the solution of simultaneous equations becomes necessary, and much needless labor is introduced. In this case assume the total load concentrated at the center of the section; then its moment about S_2 would be:

$$\left(D_2 + \frac{L}{2}\right) I$$

The moment of the load I_1 at S_1, which would just balance this moment about S_2, is:

$$(D_1 + L + D_2)\, I_1$$

Equating and solving, we get the load on S_1 equal to

$$I_1 = \frac{D_2 + \frac{L}{2}}{D_1 + L + D_2} I \quad (2)$$

which shows that the load on one station is equal to the total section load, multiplied by a fraction whose numerator is the distance from the second station to the center of the trolley section, and whose denominator is the distance between the stations.

The location of the point of division of load is readily determined. Since the load is uniformly distributed, we get

$$L_1 = \frac{I_1}{I} L \quad (3).$$

The maximum drop occurs at P and is

$$E_1 = r\left(D_1 + \frac{L_1}{2}\right) I_1 \quad (4).$$

A second type of tie section is one in which the main feeder between stations does not parallel the trolley section throughout its length, as shown at O, in Fig. 10. The loads on the three parts of the trolley section are C_1, C_2, and C_3. We then have:

$$I = C_1 + C_2 + C_3 \quad (5).$$

To find the load on S_1 we take moments as before about S_2, which gives:

$$C_1 D_2 + C_2\left(D_2 + \frac{L_2}{2}\right) + C_3 (D_2 + L_2) = I_1 \ (D_1 + L_2 + D_2).$$

Multiplying out and factoring, we get:

$$(C_1 + C_2 + C_3)\, D_2 + C_2 \frac{L_2}{2} + C_3 L_2 = I_1 (D_1 + L_2 + D_2),$$

which, by use of (5) reduces to:

$$ID_2 + C_2 \frac{L_2}{2} + C_3 L_2 = I_1 (D_1 + L_2 + D_2),$$

and hence

$$I_1 = \frac{ID_2 + C_2 \frac{L_2}{2} + C_3 L_2}{D_1 + L_2 + D_2} \quad (6).$$

The load distributed over the distance X is $I_1 - C_3$, and since the distribution is uniform, we have

$$X = \frac{I_1 - C_3}{C_2} L_2 \quad (7).$$

The drop from S_1 to the point of division P is then

$$E_1 = (I_1 - C_3) \frac{r\ x}{2} + I_1 D_1 r \quad (8)$$

which is the maximum drop on the feeder, but which may be exceeded at the ends A and B of the trolley section.

As an aid in making calculations in these and similar cases, there was prepared a series of curves as shown in Fig. 9. The radial lines represent the relation between lengths and resistances for various sizes of cables. The other set are curves of equal drops, and show the product of various resistances and currents. There are five elements entering into the curves: circular mils, current, drop, distance and resistance, and the curves are so related that the desired quantity may be read directly from the chart when the other values are known.

The method as given here has been found to be very satisfactory in practice. The results are obtained without any "cut and try" process, and by a little familiarity with the method, it is possible to work quite rapidly. The final results show those facts which it is usually necessary to know, viz., the division of load between stations and the maximum drop on the cable.

DISCUSSION.

Mr. D. W. Roper, M. W. S. E.: As the speaker was reading the carrying capacity of the several sizes of lead-covered cables, I wondered how the maximum carrying capacity of the cable was determined; for instance, for rubber insulated 1,000,000 c.m. lead-covered cable, the maximum capacity was given as 800 amperes; does not that mean 800 amperes steady load, and is this load supposed to last for one hour or two hours corresponding to the peak of the load of the Railway Co., or in what manner is it determined?

I am interested in those figures, because we run our single-conductor paper insulated cables of the same size at a load at least 20% higher without any apparent injury. After the cables had operated such loads for a month or two we carefully examined them in order to see how badly they had been injured. We cut sections out of the cable at two locations and tested them in the laboratory. These tests indicated that the cable was apparently just as good as new. Somewhat later we had occasion to run another cable at a load even greater. In this case the lead sleeves covering the joints of the cable had collapsed, due to the paraffine filling of the sleeves having melted and run into the cable. This load was considerably beyond the figures given by the speaker, and aside from these sleeves covering the joints, there was apparently no injury to the cable. I am therefore wondering whether the limits as given in the paper were determined by theoretical considerations of the rise in temperature of the time, or by practical considerations.

Mr. Rice: The cable-carrying capacity was determined by a process of elimination and comparison. The safe current-carrying capacity, or what was considered safe current-carrying capacity, by various authorities was found and, taken in connection with the probable life of the cable, was put on a safe conservative basis. These figures were arrived at in that way, not dircetly as the result of a test or directly as the result of any complex theory. It was simply the judgment as to what was a safe, conservative figure. The load, as given, is for continuous current capacity.

Prof. Woodworth, M. W. S. E., *Chairman:* I judge, then, from Mr. Roper's remarks, that if a cable were carried very much beyond that safe load capacity for any length of time, the probability is, the cable would break down. The factor of safety is quite close.

Mr. Roper: I might add that the load we carried on the cables would, I imagine, result in only a slightly increased heating over what Mr. Rice figures here as continuous loads. I had, in making my remarks, assumed that they were taken for a load corresponding to the load curve we were shown for the railways. But if the capacity of the paper-insulated cable is taken as 1,000 amperes continuous, that would probably be within 10% of the capacity to which I referred as having been such as to cause disturbances to the joints and other mechanical troubles with the cable sheath. I should think if that were 1,000 amperes continuous, it would be pretty close to the ultimate safe capacity of the cable.

Mr. E. N. Lake, M. W. S. E.: I was thinking, while Mr. Rice was talking, that it was not so very long ago, perhaps two years, that Mr. Rice complained of not being able to find any particular literature on the subject of distribution systems for large street railway systems. I am sure you will all agree with me that he has produced, as evidenced here tonight, some very good literature upon this subject.

I had four or five items that I thought I might discuss, but I see that he has covered all of them except possibly one, which I think, out of the kindness of his heart, he left perhaps, just for my use, and that is one that might be of some interest. I will simply call your attention to it. It is this: Based upon 1,000,000 circular mil lead-sheathed cable, with the assumed load of 800 amperes maximum, and the limit of drop established as 50 volts, 6,000 feet approximately is the point to which carrying capacity governs. Beyond that point it is a matter of drop, so that theoretically the ideal system would be one in which the sub-stations were so located that approximately the average length of feeder would not exceed 6,000 feet. As I remember, the average length of feeders on two of the largest systems here in Chicago is something like that, say, 6,000 or 7,000 feet, so that the conditions are pretty close to the ideal.

Mr. H. M. Wheeler, M. W. S. E.: In re-designing the feeder system of the Chicago Railways Company, the writer has developed the following graphical methods, and has found his results to check very closely with the more elaborate theoretical method just described.

The general problem may be stated thus: (1) To divide the trolley system into sections; (2) To determine the load on each section; (3) To obtain the proper size of positive feeder for each section. These points will be taken up in order.

1. To divide the trolley system into sections. (a) On map of trolley system, place dots at locations of the various power stations, join these by straight lines and draw perpendicular bisectors to same. These bisectors will form irregular polygons about each of the power stations, thus determining the territory most economically fed by it. (b) The actual length of street to use for a section depends upon the district, distance from power station, estimated load, etc. For most purposes use:

TABLE 1. APPROXIMATE LENGTHS OF SECTIONS.

Downtown District, ¼ mile of street equals ½ mile single trolley
Adjacent District, ½ mile of street equals 1 mile single trolley.
Crosstown Lines, 1 mile of street equals 2 miles single trolley.

Of course, if further calculations show the load on any section too light or too heavy, the section can be lengthened or split accordingly.

2. To determine the load on any section. It will be convenient to obtain this load in cars. This load equals length of section (single trolley) multiplied by the cars per mile (for assumed schedule speed and headway). Schedule speed will be expressed in miles per hour (M. P. H.) headway in minutes; distance between cars in feet. The cars per mile are obtained from curves in Fig. 1, which will now be described. (a) Fig. 1. On cross section paper, lay off scales with feet as ordinates, and number of cars as abscissae. Assume cars spaced uniformly, whence we plot curve C D using:

TABLE 2. DISTANCES BETWEEN CARS.

At 2 cars per mile, distance between cars equals 5,280 ÷ 2 = 2,640 feet.

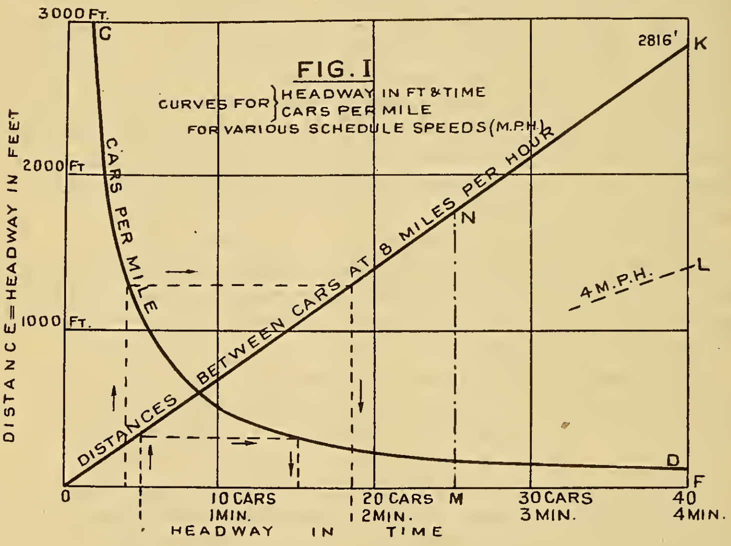


FIG. I

CURVES FOR } HEADWAY IN FT & TIME / CARS PER MILE FOR VARIOUS SCHEDULE SPEEDS (M.P.H.)

At 4 cars per mile, distance between cars equals 5,280 ÷ 4 = 1,320 feet.

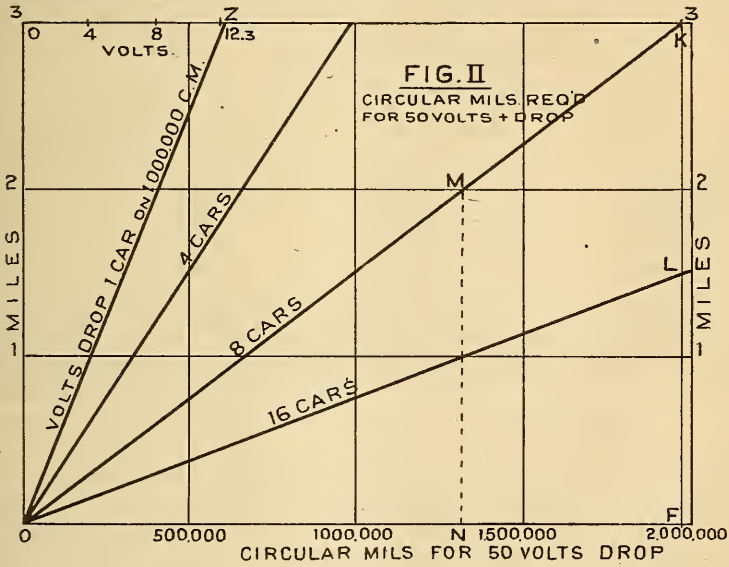
At 10 cars per mile, distance between cars equals 5,280 ÷ 10 = 528 feet.

Note: Find other distances in the same manner.

This curve C D is seen to be a rectangular hyperbola of which the equation is C D = 5,280, when C = cars per mile, and D = distance between cars.

(b) We have now to obtain the relationship between cars per mile and schedule speed and headway. (Fig. 1.) Lay off second horizontal scale for headway in minutes. At 8 M. P. H. and 4 minutes headway, the distance between cars is feet per minute times 4, or $\frac{8 \times 5280}{60} \times 4 = 2816$ ft. This establishes point K, on F K the 4 minutes ordinate. Draw O K. Then O K is the 8 M. P. H. Locus, *i. e.*, the ordinates below O K are the distances corresponding to the headways. To prove this, take any headway O M and draw ordinate M N, cutting O K at N, and let X be corresponding distance. For same schedule speed, distance between cars will vary as the headways, whence X : F K = O M : O F, but from similar triangles M N : F K = O M : O F ∴ X = M N.

The line O K is plotted to distance and headway; the curve C D is plotted to distance and cars—distance being to same scale



on each. We pass from one to the other at equal distances, *i. e.*, by horizontal lines. Example: Assume ½ minute headway, project up to line O K, thence horizontally to curve C D, thence down to cars, and obtain 15 cars per mile at 8 M. P. H. By assuming 4 cars per mile and reversing the process, we obtain a headway of 1 minute 52 seconds.

(c) Since for constant headway, distances will vary as the schedule speeds, the 4 M. P. H. Locus will cut F K at L = ½ F K; the 16 M. P. H. Locus at P = 2 F K, etc.

(d) Where two car lines run over the same track, the combined headway $= \frac{H\ h}{H + h}$, where H = headway of first, h = headway of second.

(e) TABLE 3. SCHEDULES AND HEADWAYS.

Downtown District—4 M. P. H.—1 minute headway.
Adjacent District—8 M. P. H.—1 minute headway.
Crosstown Lines—8-12 M. P. H.—4-6-8 minutes headway.

(f) Multiply cars per mile S (2) by length of section S (1) and obtain load in cars to use in S (3).

3. To obtain the proper size of positive feeder for each section. (a) When cars are uniformly distributed over a section, the drop at the end of the section is the same as the drop when all the cars are bunched at the middle of the section. For purposes of drop, find length of feeder by taking routed distance from power station to the middle point of the section. Assume 75 amperes per P. A. Y. E. D. T. car, 50 volts maximum positive drop and carrying capacity of cable as per table below (adapted from Board of Supervising Engineers).

TABLE 4. CARRYING CAPACITY OF L. C. CABLES.

Circular Mils.	Insulation.	Amperes	Number of cars load.
1,000,000	5/32″ Paper	1,000	13
1,000,000	5/32″ Rubber	800	11
500,000	5/32″ Paper	600	8
500,000	5/32″ Rubber	500	7

(b) Fig. 2, plot miles vertically, circular mils horizontally One mil-mile of copper has resistance of 54,674 ohms. To obtain feeder for 8 cars, 3 miles distant, 50 volts drop, apply ohms law

$$E = I\ R, \text{ remembering that } R = \frac{\text{length x resistance per mil-mile}}{\text{circular mils}}$$

Whence $50 = 8 \times 75 \times 3 \times 54{,}674 \div$ circular mils; solving, circular mils = 1,968,264. Plot point K at 3 miles, 1,968,264 circular mils; draw O K. This line O K gives relationship between length (of feeder) and circular mils for 8 cars. Example: at 2 miles find point M on O K, project down to N on base line and obtain 1,300,000 C. M. as size of necessary positive feeder. As this is an odd size, and as 1,000,000 C. M. cable has ample capacity (Table 4), we can use 1,000,000 C. M. cable, but the drop will then be inversely as the circular mils, *i. e.*, 13/10 of 50 volts = 65 volts. If 1,500,000 C. M. cable is used the drop will be 10/15 of 50 = 33 volts. As an additional check, use line O Z, which shows relationship between miles (length of feeder) and volts drop for one car on 1,000,000 C. M. feeder. In example above for 2 miles, drop per car = 8.2 volts, whence for 8 cars = 65.6 volts.

(c) Since for constant size of feeder and constant drop the load will vary inversely as the length, the 16 cars line will cut F K at L = ½ F K; the 4 cars line at P = 2 F K, etc.

(d) In general, feeders should go by the most direct route and should never feed back. The 1,000,000 C. M. cable is the most convenient size and will scarcely ever carry sufficient overload to endanger machines at the station.

(e) When sections are bussed between two stations, either feeder should be able to carry the section alone. When both such feeders are working, the net drop will equal the product of the separate drops, divided by their sum, or $X = \frac{V\ v}{V + v}$.

IMPROVEMENTS SUGGESTED IN UNDERGROUND CONDUIT CONSTRUCUION FOR LARGE TRANSMISSION SYSTEMS.

Edw. N. Lake, M. W. S. E.

Presented February 23, 1910.

I. General.

1. *Introduction.*

The use of ducts for installing electric conductors underground is a practice of comparatively recent years. The ducts were primarily a means for placing cables underground and a convenience for repairing and replacing them. In more recent times, however, with the large increase in the amounts of energy transmitted, the additional feature—isolation of the cables—is exceedingly important.

In a very few years' time we have seen the rise and fall, so far as large systems are concerned, of a large number of different forms of ducts. The various forms of wood and the pump log type, the Dorset asphaltic concrete forms, the 10 by 10 in. terra cotta, shown in Fig. 1, are now all practically obsolete and the iron pipe and cement lined pipe are only rarely to be found at this time. The forms at present used are the cement or stone duct, fiber pipe, and the multiple and single form of vitrified clay duct. All of these forms of duct are installed in the same general manner in concrete, and the methods are practically the same as have been used for fifteen or more years.

A change or an improvement in underground conduit construction, because of the effect of precedent and inertia is sure to encounter strenuous objections all along the line. The men in the trench who handle the material and lay the duct; the gang bosses and foremen who are responsible for progress and labor costs; the men who install the cables; the man who is held responsible for the safety of the cables when in place; and the man who is responsible for the investment made, will all have their say—will all "take a shot at the new stunt," as they say, and the new plan must show some very decided advantages or it will not be able to run the gauntlet of criticism and reach the point where someone in authority will say that it is worth trying out..

The suggested improvements in this paper are almost all made with reference to the comparatively new ideas of isolation and protection of the cables for which the conduits are built. In this as in all other matters of engineering design, where prevention and insurance are the basis, the precautions taken and the amounts expended for safeguards will depend entirely upon the importance which is attached to these matters by the men who are responsible for the designs and the expenditures. Numerous cases of burnouts which have seriously affected a larger or smaller number of cables adjacent to the defective one can be cited by almost any engineer who has had to deal with underground conduit installations for the distribution of large amounts of electrical energy. So there is apparently a real need of some improvements which will insure against such spread of *trouble* from one duct to another.

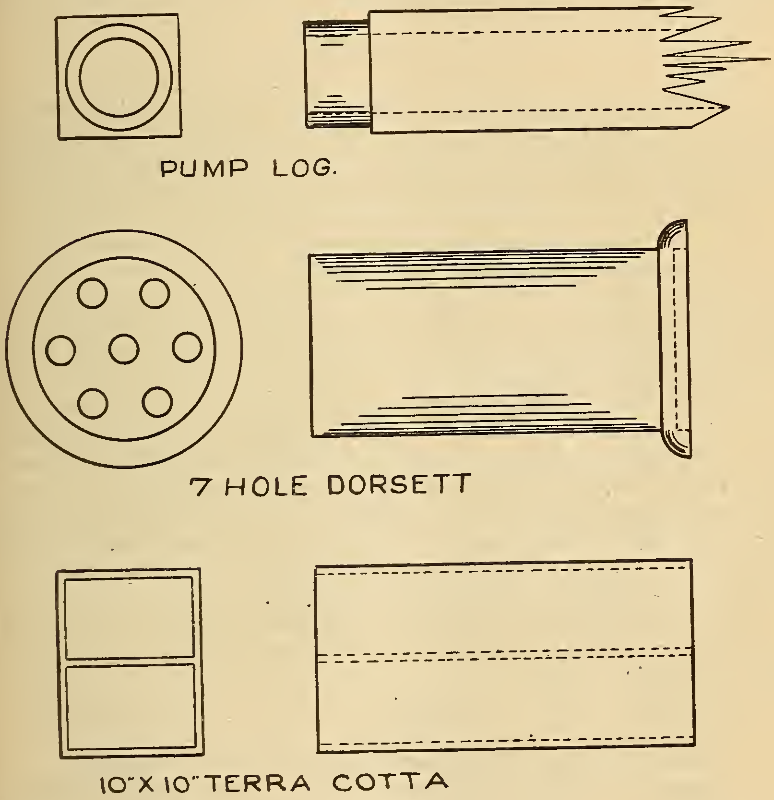


Fig. 1.—Some Obsolete Forms of Duct.

2. *Vitrified Clay.*

The best heat-resisting and arc-resisting material which is available on a commercial basis at this time is undoubtedly vitrified clay.

Where a materal is desired for use in contact with flame or intensely heated gases, as in furnace linings, boiler bridge walls, or flue linings; where a receptacle is wanted in which to enclose a high tension insulator when it is placed in the kilns; where a material is to be subjected to the great volume and intensity of heat that emanates from molten metals; everywhere that heat and flame are to be resisted by direct contact, some form of hard-burned clay is used. So when a material is wanted for underground conduit construction that will resist the intensity and volume of the heat of the electric arc, we very naturally turn to vitrified clay in the form of ducts.

3. Absorption Tests.

When a small quantity of water is closely confined and exposed to sudden and intense heat, it acts with all the violence of a high power explosive. Tubular steam boilers without water and with the bottom plates overheated have exploded with most terrific force upon turning in only a small quantity of feed water. A drop or two of water in a ladle into which molten metal is poured explodes with disastrous effects. A very small amount of water confined in old scrap castings, such as old pump valves, when not properly broken up and inspected before being thrown into the melting furnace, has been known to explode with force enough to wreck a cupola.

Due to this so-called explosive power of water, it is believed that the walls of a clay duct, which might otherwise withstand the heat of a burnout, if it contains a sufficient amount of moisture, will be rapidly disintegrated in successive layers by the sudden vaporization of the water confined in the interstices, under the action of the intense heat of the arc. Hence, that vitrified clay duct is best for large power distribution systems which will absorb the smallest percentage of moisture.

The following, it is believed, represents in a general way the relation of vitrification and glaze to absorption in this class of duct material:

Vitrification.	Glaze.	Absorption.
Good.	Good.	Minimum.
Good.	Poor.	Slightly larger.
Poor.	Good.	Larger.
Poor.	Poor.	Maximum.

You will see from these relations that if an absorption test is made a part of the duct specifications, the percent for a whole piece of tile will differ from that of a fragment, and the fragments will differ with the amount of glazed surface.

A ready means of testing absorption is to take a sliver from a broken duct, preferably one with one surface glazed, and dip it in ink. By breaking off fragments from the tip end, the following will then be observed:

1. If glaze and vitrification are good, the ink will not penetrate the material.

2. If glaze is good and vitrification is poor, the ink will not penetrate through the glaze, but will penetrate a considerable layer of the unglazed material.

3. If glaze and vitrification are both poor, the penetration will be about the same on all surfaces.

The percentage of absorption permitted will depend upon the importance which the engineer attaches to the matter, and the local conditions as to the kind of duct that can be delivered to the trench at a fair price.

One specification used here in Chicago requires not more than 2% absorption in 24 hours in the whole piece, and 3% in fragments having about 50% of surfaces glazed. Another specification requires not over 5% absorption, without defining the condition as to the whole or broken pieces.

II Conduit Construction

4. Single Duct and Multiple Duct

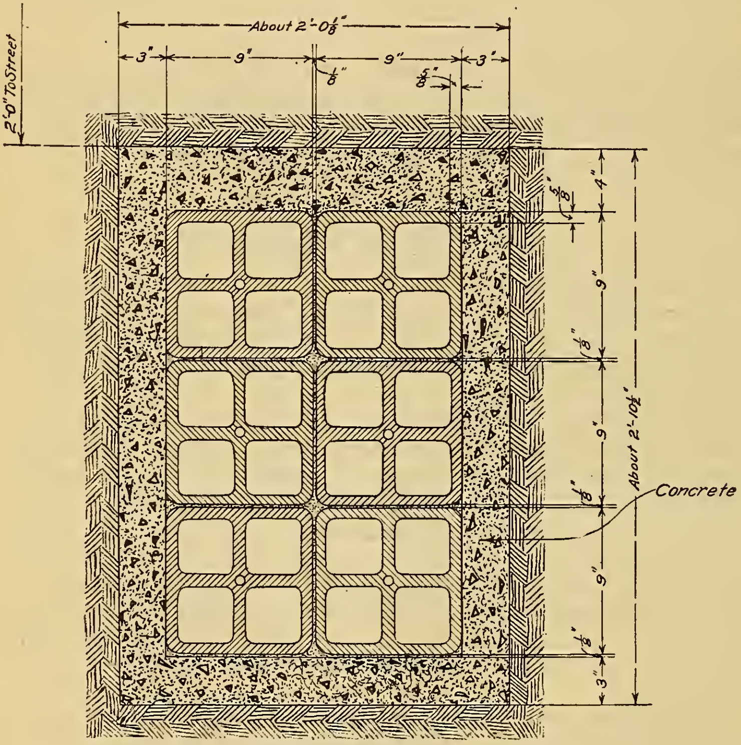
This is an old subject and practices are pretty well crystalized with reference to the use of single and multiple duct; each has its particular field in which it practically monopolizes the construction, but a word here may not be entirely at variance with the scope of this paper.

For telephone cables, and for all cable systems where the number of heavy cables is not large and where no special consideration of the possible spread of trouble from one cable to its neighbors is thought to be necessary, the multiple duct, Fig. 2, on account of economy of space and convenience in handling, is the logical choice of vitrified clay duct. But for systems which carry large groups of cables where tens of thousands of kilowatts may be concentrated upon a burnout, and where cable separation and isolation must be given its due consideration, the single duct construction, Fig. 3, is believed to be better and is most generally used.

It might be said, in passing, that the single duct is a much more flexible construction for congested city locations where a great deal of maneuvering is necessary to get around or over, or under, or through obstructions. These obstructions, which are the uncharted reefs of the underground territories of any city, are both the joy and the grief of underground conduit work. If it were always a clean ditch, such as Fig. 4, and with no obstructions, underground conduit construction would be monotonous and uninteresting. If it were not for the difficult intersections, of which Fig. 5, reproduced from the *Engineering Record,* is a good example, and the satisfaction of getting a good line through them, some of the men who have followed the work for half a lifetime would have dropped out long ago.

5. The Corners of the Duct.

The present standard single duct construction, using 3¼ or 3½ in. square bore duct, which is used in most of the larger systems, is shown by Fig. 3, and is believed to represent the best engineering practice for large power systems at the present time. This construction, when properly installed, provides two walls of about ⅝ in. each of vitrified clay between adjacent ducts, and it has been demonstrated in practice that for ordinary burnouts this is effective in isolating the trouble. In the case of very severe burnouts it has been found, however, that there are certain weaknesses in this form of construction. One of these is due to the present form of corners on the duct, which leaves a void of considerable size. Of the space shown between the corners in Fig. 6, only the lower half is usually filled with concrete, so that a severe burnout will communicate laterally through the joints in the ducts and longitudinally through the voids, and thus injure cables in adjacent ducts.



SECTION THROUGH CONDUIT

Fig. 2.—Multiple Duct, Standard Construction.

In Fig. 7 is shown an example of this defect, taken from a drawing exhibited by Mr. D. W. Roper, of the Commonwealth Edison Company, of Chicago, in a paper which he presented here something over a year ago. It is apparent that burnouts of this kind involve a large expense to repair the cables and ducts; the danger to connected apparatus is also a factor to be considered, so that improvements which may be made at a reasonable cost which will reduce the liability of such loss are very desirable.

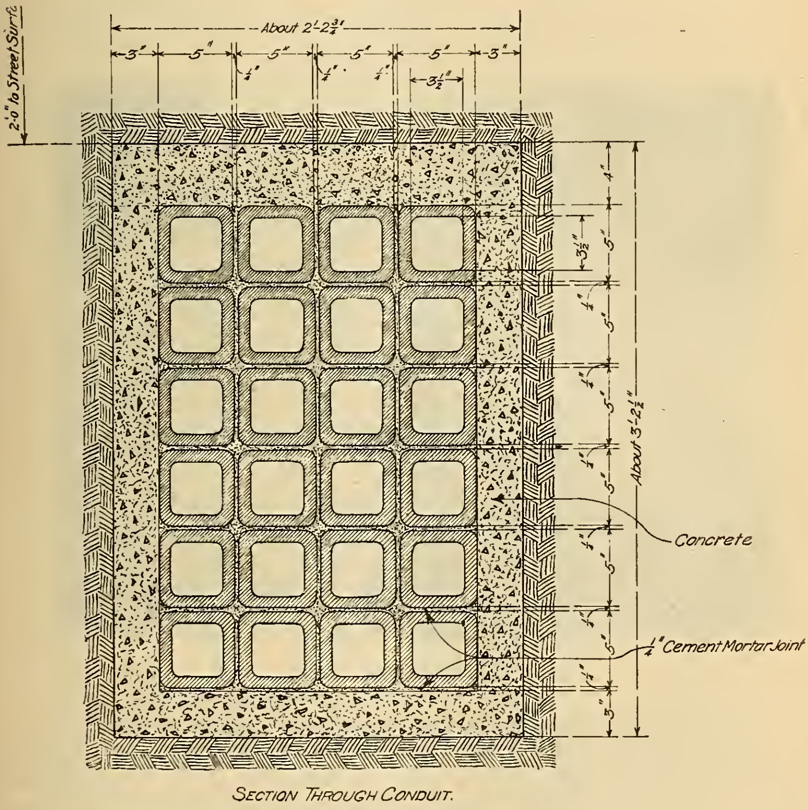


Fig. 3.—Single Duct, Standard Construction.

It is believed that one simple improvement in the duct would consist of slightly modifying its shape so as to reduce the void at the corner to such an extent that it may be completely filled by the mortar in the process of laying. By comparing Figs. 6 and 8 it will be seen that by a slight change in the outside radius of the corner of the duct, the area of the void at the corner of four ducts is very materially reduced. By going over the drawings with a planimeter, it was found that this corner space was in a ratio of six on the present form to one on the proposed form.

This change in form was submitted to several of the leading duct manufacturers, and while all agreed that it was not impractical to manufacture the duct in the proposed form, there were the usual objections that are urged to any innovation. The following are extracts from the letters received.

Manufacturer No. 1, First Letter.

"In direct answer to your inquiry, we may say that it is possible to manufacture your proposed form, but that we have given our present form as square a corner as is economical in manufacture. We estimate that it would cost at least 3% more to manufacture your proposed form on account of the additional waste which would be caused in the machine running.

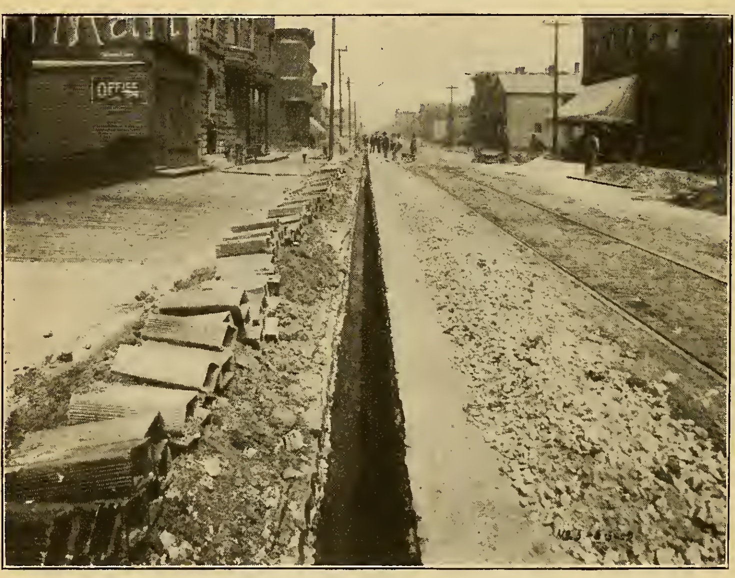


Fig. 4.—A "Clean Ditch."

It is necessary to run the clay very stiff to manufacture this particular form of conduit. With stiff clay the nearer you approach a square corner the more apt is the clay to scale up on the dies. The result would be a roughened cross-cracked corner, which would not be acceptable and would have to be culled out."

Manufacturer No. 1, Second Letter.

"It would be to your advantage, in the contemplated change of style of conduit, not to require any change on the inside corner of the duct. In trimming the tile to bevel the inside edges of the duct, the square corner would be apt to be slighted in the trimming.

On advice from our superintendent at the factory I may say that we can make this outside change as per your blue print."

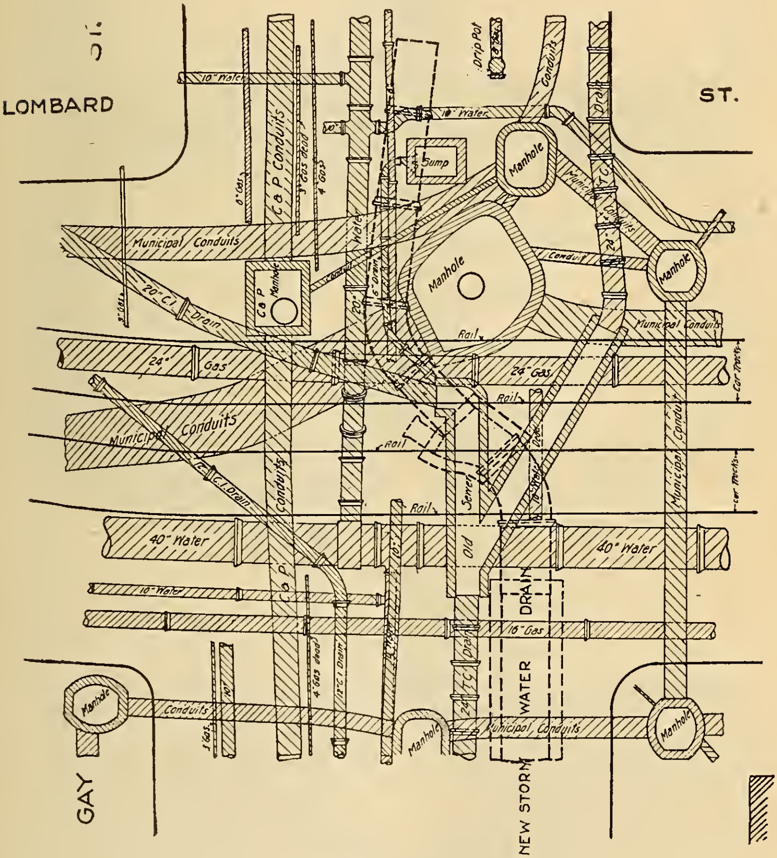


Fig. 5.—"A Difficult Intersection."

Manufacturer No. 2, First Letter.

"We see no practical objection to the tile being manufactured in the form called for by your design, excepting, of course, new dies would be required in order to manufacture the tile in the exact shape called for."

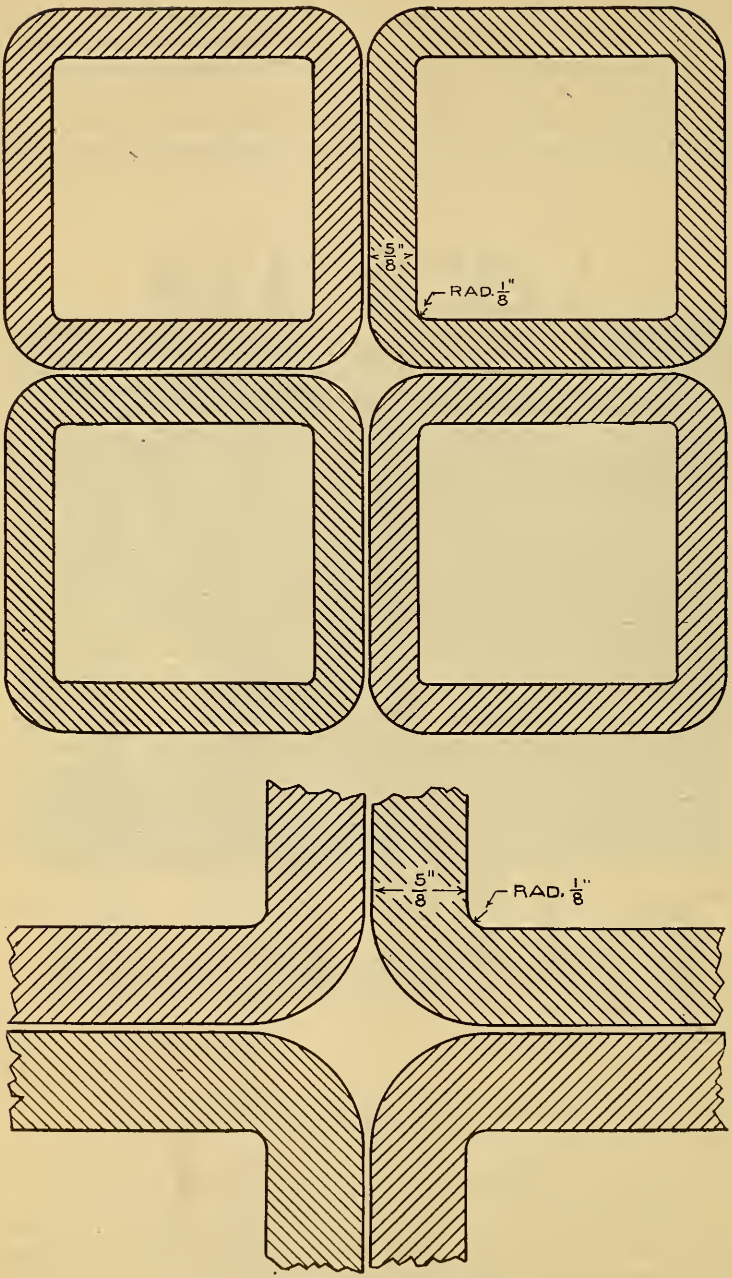


Fig. 6.—Present Form of Corners of Clay Ducts Showing Large Voids.

Manufacturer No. 2, Second Letter.

"Since my former letter I have consulted with our factory superintendent more fully, and he is quite adverse to changing the present form of our 3½ in. square conduit in accordance with your sketch, for the reason that the unequal thickness of the shell at the corner will materially retard the drying of these conduits, to what extent we cannot say until some of the blocks are manufactured, and whether or not an increase in cost would result therefrom for this reason is problematical."

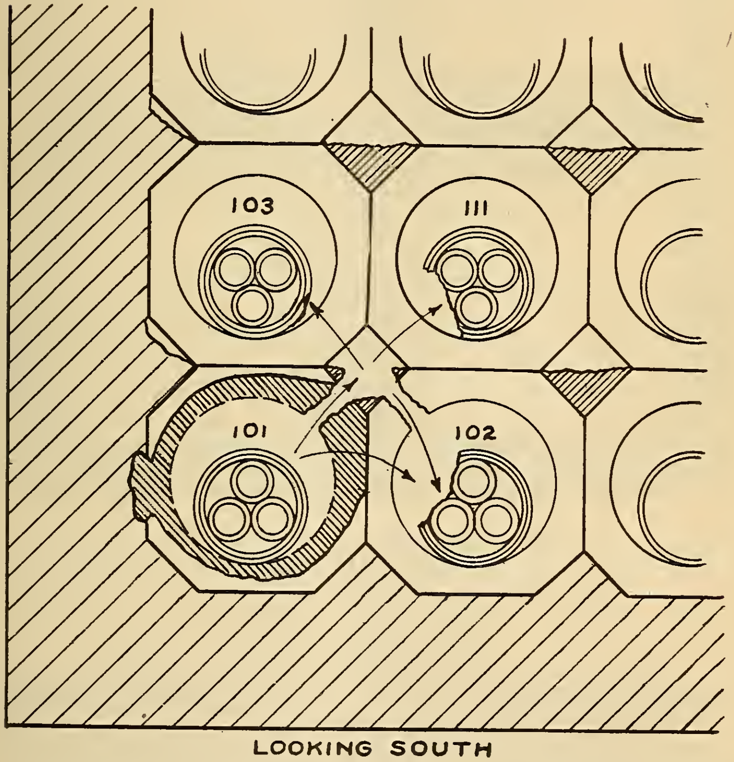
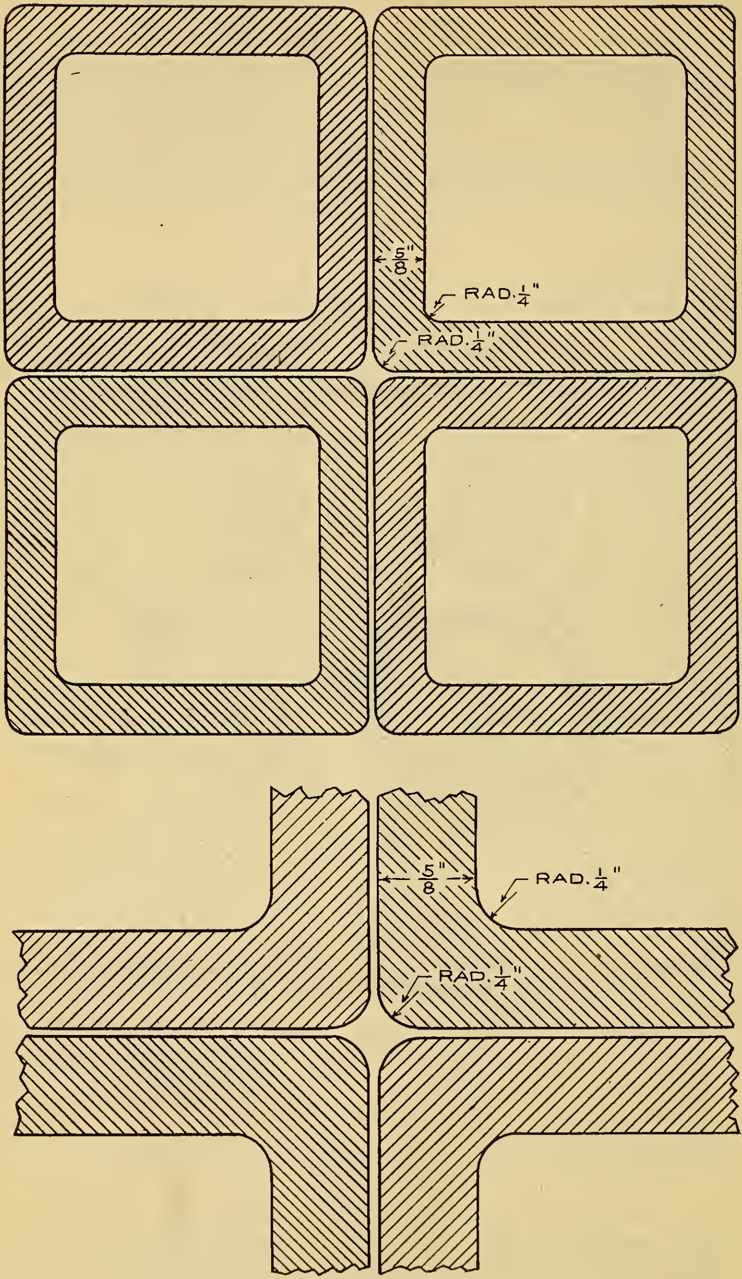


Fig. 7.—Example of Burnout, Spread of Which Was Apparently Due to Large Voids.

Manufacturer No. 3.

"Upon a recent visit at our factory our superintendents were consulted, and it was the general opinion that the section could be made, but not without an unusually large percentage of loss in the manufacture, because of the inclination



FULL SIZE

Fig. 8.—Suggested Form of Corners of Ducts With Small Voids.

of clay wares to move during the burning period, and thus make the finished product undesirable, because of its having lost its shape."

Manufacturer No. 4.

"This type of conduit can be manufactured as easily as any of the present standard types of single conduits. Its cost of manufacture would be greater, however, due to the much larger amount of clay in its ends than in other types, causing uneven shrinkage and flaring of the ends in the drying out process, and a splitting and cracking of the ends in the burning process.

The conduit would necessarily be heavier than other types of singles and the process of manufacture would be slower. The additional cost in manufacture over the other types would be approximately ¼c per duct foot, and its manufacture would not be profitable on small amounts as it would materially interfere with our output of standard conduits."

From the foregoing and from conversations with the manufacturers' representatives, it is apparent that some considerable inertia must be overcome, but it is quite certain that if competitive bids were requested on a large quantity of duct with the proposed form of corner, it would be found that the manufacturers would be willing to make the duct without any additional cost over present forms, and it is very probable that the product would be just as good as the material in the present form of duct.

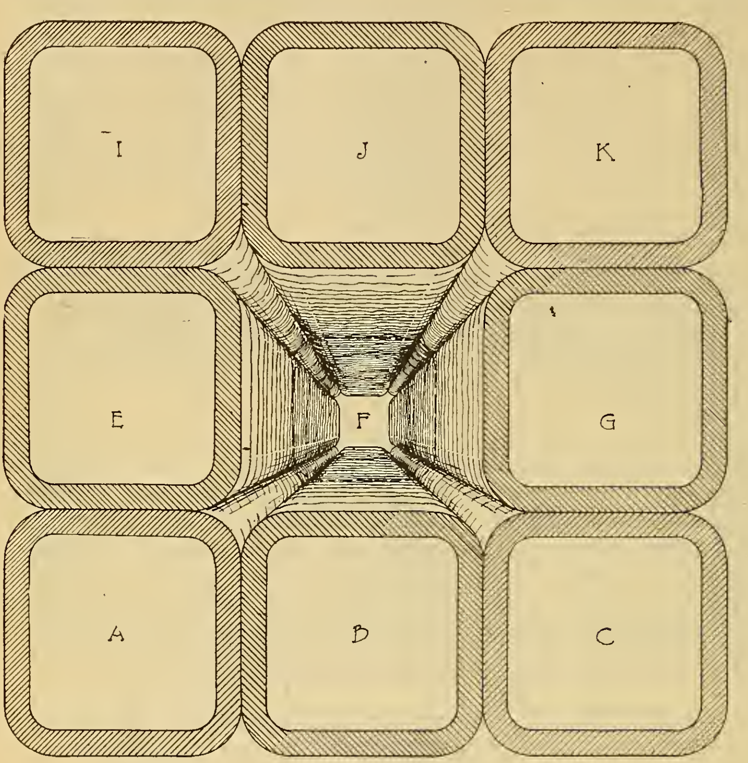
6. *Definite System of Breaking Joints*

Another difficulty encountered in the present construction is that, unless very careful supervision is exercised, the joints in the ducts will not be properly staggered as they are laid.

Take, for example, the middle duct in a 9-duct section, as duct *F* in Fig. 9 which has eight ducts adjacent, whose joints must be staggered with reference to its own joints. This is usually done so far as the four ducts adjacent to the four sides are concerned, as ducts *E, J, G,* and *B*, but it often occurs that the ducts adjacent to the corners, such as *I, K, C* and *A,* have not their joints properly staggered.

The result of this is that burnouts may occur in a duct, say duct *F,* which would not affect cables in the ducts *E, J, G,* or *B,* but would melt the lead and destroy the insulation of cables in ducts *I, K, C,* and *A*.

A rigid adherence to a definite plan of breaking joints is not usually followed, but would be of decided advantage in the present construction. For a conduit section of tiers of four ducts in width, the plan shown on Fig. 10 is effective. This is so arranged that joints in adjacent ducts will not be nearer than one-fourth of a standard length, or 4½ in. apart. While this would undoubtedly reduce to some extent the liability of the spread of a burnout, the spacing of 4½ in. minimum between joints in adjacent ducts is manifestly too small, even if it could be rigidly maintained, which is extremely difficult under practical construction conditions.



SECTION THROUGH DUCT
CENTER DUCT REMOVED

Fig. 9.—A Group of Ducts, With Center One Removed to Show Necessity of Breaking Joints.

7. *Single Duct in Multiples*

One improvement which has been considered consists of installing the present single duct in multiples, with an extra separation by concrete between the multiples. In Fig. 11 is shown a section of this construction, and Fig. 12 shows the corresponding plan of breaking joints. This construction does not overcome entirely the objection due to voids at the corners, and since joints will be as close as 4½ in., a cable failure may involve adjacent ducts in the same group, but it has the advantage of dividing up a conduit line into unit groups which are so thoroughly isolated that the possibility of a cable failure in one group injuring the cables in an adjacent group is very remote.

8. *Single Duct in Tiers*

Another plan, shown in Fig. 13, is a modification of the

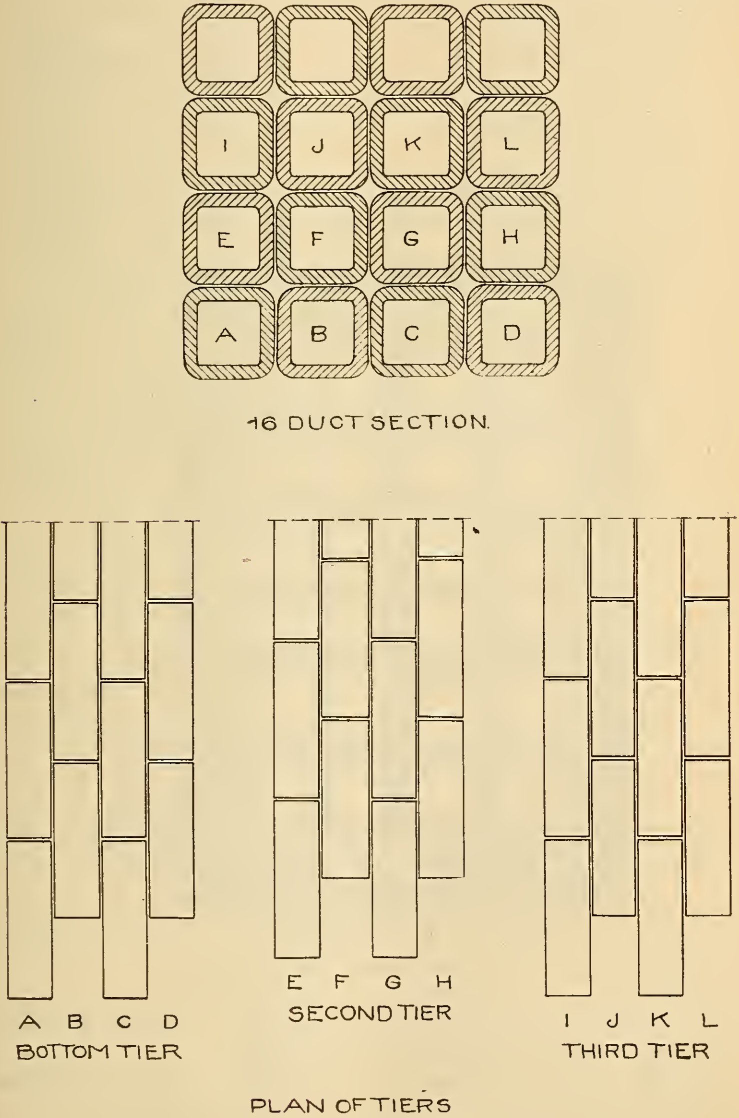


Fig. 10.—Plan of Breaking Joints, Single Duct, Standard Construction.

above, in which the multiples are in horizontal tiers. Each tier is separated by a substantial layer of concrete. This form is a little more simple in construction, since the layer of concrete between tiers can be spread wet enough to make tamping unnecessary and no spading is required.

This plan possesses the following advantages over either of the other two plans:

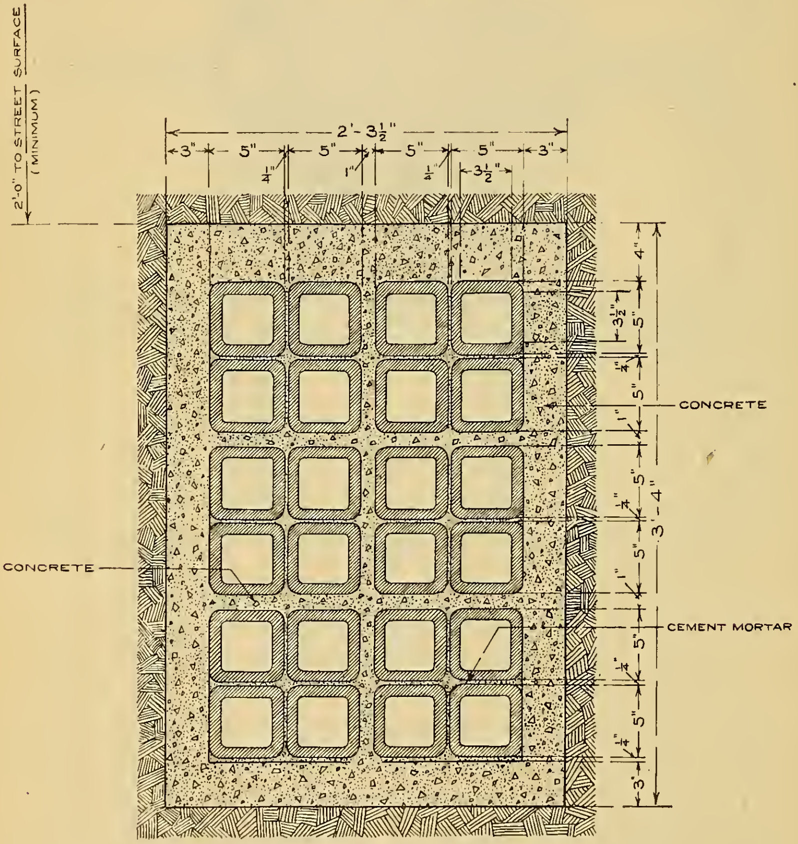


Fig. 11.—Single Duct Laid in Multiple.

1. As shown by Fig. 14, no joints in adjacent ducts are closer than a half length, or 9 in.

2. The voids at the corners will be very largely eliminated with the present form of corners, and entirely done away with if the proposed new form is used.

3. The cables in the unit tiers are very effectively isolated

by two ⅝ in. thicknesses of vitrified clay and 1 in. or more of concrete.

Practical conduit men will look askance at figures upon cost since there is such an exceedingly wide variation in costs, due to soil, obstructions encountered, weather conditions, and the organization of the conduit gangs. Comparative figures, however, based as nearly as possible upon similar conditions, are here presented to show the relative costs in cents per duct foot of the three different methods of conduit construction.

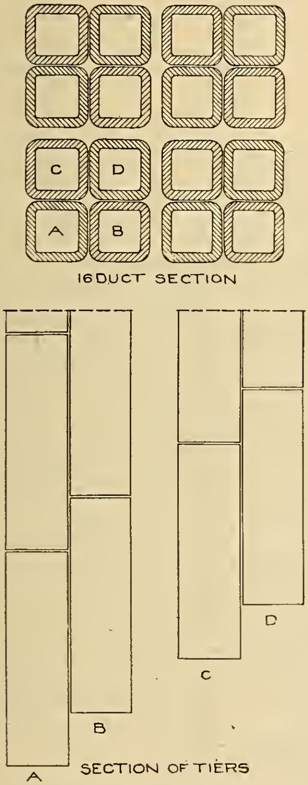


Fig. 12.
Plan of Breaking Joints for Single Ducts in Multiple.

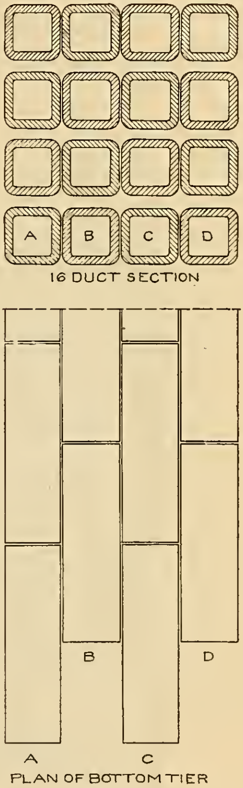
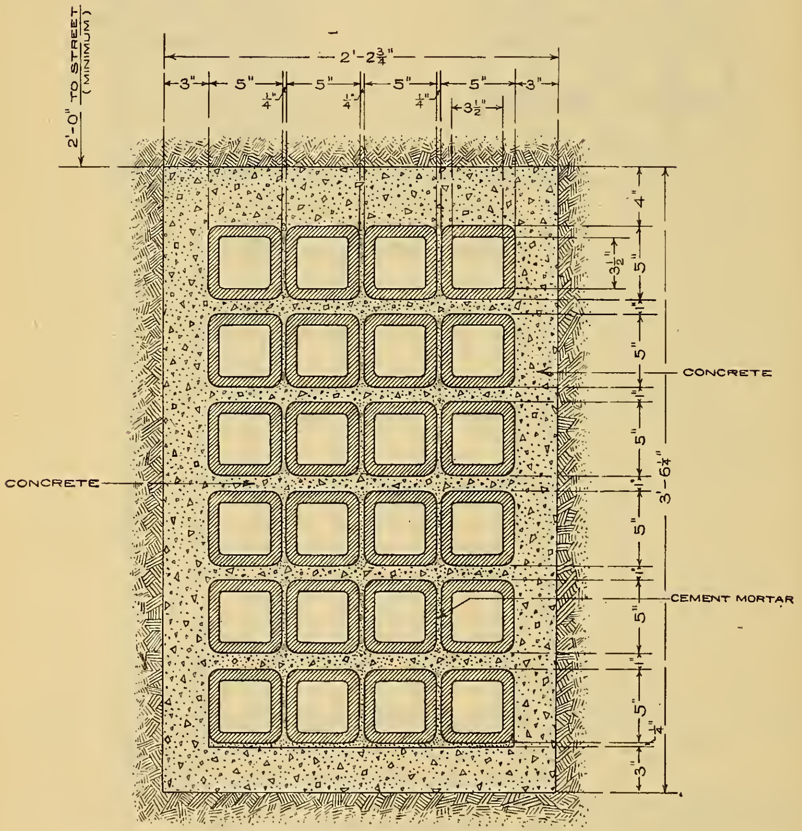


Fig. 14.
Plan of Breaking Joints for Single Ducts in Tiers.

Conduit Section	Standard Single Duct (Fig. 3)	Single Duct In Multiple (Fig. 11)	Single Duct In Tiers (Fig. 13)
4 Duct	27.6	27.6	28.1
6	22.0	22.1	23.0

8	19.3	19.7	20.4
9	18.3	...	19.3
10	18.0	19.6	19.2
12	16.4	17.7	17.5
15	15.0	...	16.3
16	14.9	15.6	16.0
18	14.6	...	15.9
20	14.2	15.1	15.3
24	13.3	14.3	14.5
Average	17.60	18.96	18.68



SECTION THROUGH CONDUIT

Fig. 13.—Single Duct Laid in Tiers.

Taking the standard single duct construction shown in Fig. 3 as the base, a comparison of percentages is given below, and also in the last column is given the cents per duct foot of extra costs which would be involved in using the unit tiers.

Conduit Section	Standard (Fig. 2)	Multiple (Fig. 9)	Tiers (Fig. 11)	Extra Cost of Tiers
4	100%	100%	101.8%	.5
6	100	100.4	104.5	1.0
8	100	102.0	105.7	1.1
9	100	.....	105.4	1.0
10	100	108.8	106.6	1.2
12	100	107.9	106.7	1.1
15	100	.....	108.6	1.3
16	100	104.7	107.4	1.1
18	100	.....	108.9	1.3
20	100	106.3	107.7	1.1
24	100	107.5	109.0	1.2
Average	100%	107.7%	106.1%	1.08c

It will thus be seen that the conduit construction in tiers involves an increase for the average of all of the conduit sections considered, of about 6% or about 1c per duct foot. An increase in conduit cost of 6% would seem at first to be more than is justifiable for such improvements. But when considered as additional insurance against cable losses, it is found that the 1c per duct foot of increased cost is only a nominal insurance rate. The value of cable per foot of duct may be $1.00 to $1.50, and the connected apparatus which might be endangered by cable burnouts may be of an additional value equal to $1.00 to $1.25 per foot of cable. Taking the minimum of $2.00 per foot for the value of cable and connected apparatus as the basis, the additional cost of 1c per duct foot for construction in tiers is equal to an insurance rate of only 50c per $100.00 for the first year. The cost for subsequent years will be the interest charge on this additional cost, which at 6% would be 3c per $100.00. Upon this basis the additional cost would appear to be not only entirely justifiable but highly to be recommended.

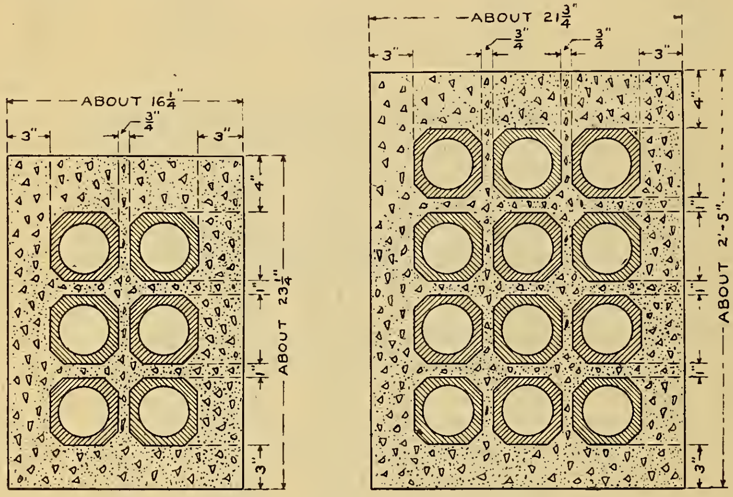
9. Round Bore Duct For Important Lines

Square bore duct has come into general use because two or more cables can be installed with greater ease than in the round bore, and because it is a favorite with the men at the trench on account of greater ease in handling and laying.

Round bore duct of the same size takes less clay to make, and is lighter in weight; there is also less waste due to swelled ends in the drying process, and a smaller number of culls from the kilns, because the shape is such that when piled for burning the heat is distributed more uniformly, and the material is therefore generally better burned and better vitrified.

In ordinary low tension systems the individual cables seldom carry more than 250 to 500 kw. each. In a high tension system, however, ten to fifteen times this capacity may be transmitted in a single cable. In high tension systems the cables are usually of such large outside diameter that only one of them can be installed in a duct. For high tension lines and for important low tension lines involving large amounts of power, where a superior construction is desired, a line consisting of round bore single ducts laid in tiers, with an extra space between horizontal ducts, as shown in Fig. 15, would represent, it is believed, the very highest type of construction possible at this date.

A comparative estimate of the cost of this construction and the present standard square duct conduit, assuming identical conditions and taking only the 6 duct and 12 duct sections, gives the following:



SECTIONS THROUGH CONDUIT
(3½" ROUND BORE DUCT)

Fig. 15.—Round Bore Single Ducts with Horizontal and Vertical Separation.

	Standard Square Bore (Fig. 2)	Round Bore Special (Fig. 15)	Extra Cost Round Bore Special
6 duct per duct ft.	22.0c	23.0c	1.0c
12 duct per duct ft.	16.4	17.6	1.2

This small additional cost would often be more than justified on the important lines of a large system.

10. *Duplex Conduit Construction*

It is the practice in recent years of those who are responsible for the safety of the cables on an extensive system, to have cables routed by as many routes as are available and practical, so as to minimize the effect of burnouts in interrupting the service on the system. Where practicable, heavy conduit runs are subdivided and built part on one street and part on another so as to make this routing of cables possible, but this involves a large additional expense since it is apparent that two 12-duct runs on different streets will cost more for excavation, manholes, concrete, and paving than one 24-duct run on one route.

In order to secure in a large measure the advantages of two separate runs with but very little increase in the cost, what is styled the duplex construction will be found to be desirable. This consists simply in dividing the conduit of a run into two sections, separated by a substantial barrier of concrete. Fig. 16 shows a duplex line of 24 ducts divided into two equal sections, with a concrete barrier of about 3 in. Where the ducts enter the manholes, this spacing is increased to 6 or 8 in. and the cables may be trained on opposite walls of the manhole. The additional expense involved for this construction amounts to only about ½c per duct foot on a 24-duct line such as shown.

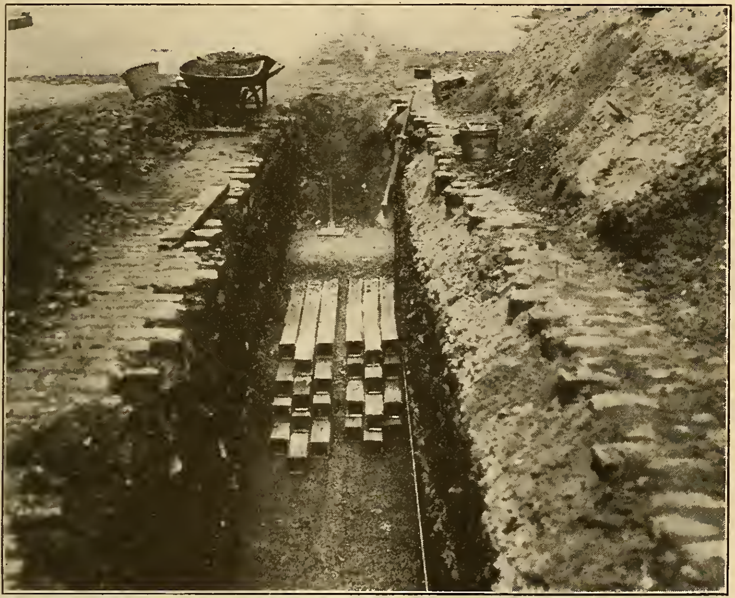


Fig. 16.—Duplex Line of 24 Ducts with a Vertical Concrete Barrier in the Center.

11. *Laterals.*

The connections which are made at intervals between the overhead system and the underground system of a street railway are made by means of taps or laterals extending from a manhole through a suitable duct up to the overhead conductor on the pole.

These laterals, although a relatively small part of the system as a whole may, if they are improperly insulated or improperly installed, become the weak points which are the measure of the effective strength of the whole distribution construction.

Present standards of construction have, in the main, proved very satisfactory, but there are some details which, it is believed, can be improved so as to eliminate a certain class of troubles.

It has been observed that the laterals are the points where the conditions appear to be especially favorable for the occurrence of trouble. An apparent cause of failures in the lateral connection is electrolysis, the effects of which are often to be found in the bends of the iron pipe through which the lateral connections are made. This is probably due to the fact that in a conduit system using vitrified clay ducts, the sheath is usually much better insulated from the earth throughout its length than at the point where the lead sheath of the lateral tap comes in contact with the iron pipe constituting the lateral duct. This pipe, if attached to an iron pole or buried in the earth at its lower end, is usually pretty well grounded, and it has been observed that very often there is a good deal of moisture at the bend. These conditions are especially favorable to electrolytic action which, by destroying the lead sheath, brings about, sooner or later, a failure of the insulation with its resulting burnout.

It may also be true that near the border between overhead and underground districts, the insulation at the laterals is subject to unusual strains on account of surges in the overhead system, encountering the capacity effect of the underground lead sheathed cables at these points. In any event, in order to minimize the trouble at these points it is believed that the insulating value of the lateral duct should be about the same as or better than that of the duct in the main conduit line.

The iron pipe lateral construction, shown in Fig. 17, does not provide any insulation, but, as above noted; does prove a danger point on the system. Consideration has been given to other possible forms which would provide some insulation for the lead sheath of the lateral cables. An essential of all lateral construction which is to be kept constantly in mind, is the thorough protection of the conductor against mechanical injury. For the vertical portion on the pole there appears to be nothing better at the present time than iron pipe, so that all of the styles considered agree in having a vertical section of iron pipe. The other illustrations are self-explanatory, showing the 3 in. sewer pipe in Fig. 18 and 3½ in. standard duct in Fig. 19, each having a cast iron adapter to connect the sewer pipe or duct to the iron pipe of the vertical run.

Fiber duct was considered for the vertical run, but it was believed that, when used without protection from mechanical injury, the liability of injuring the conductor would be too great. So a combination of fiber to provide the insulation and iron pipe to afford the mechanical protection was designed, which is shown in Fig. 20. With this construction the insulation can be carried up the vertical run, which is not possible with the other types.

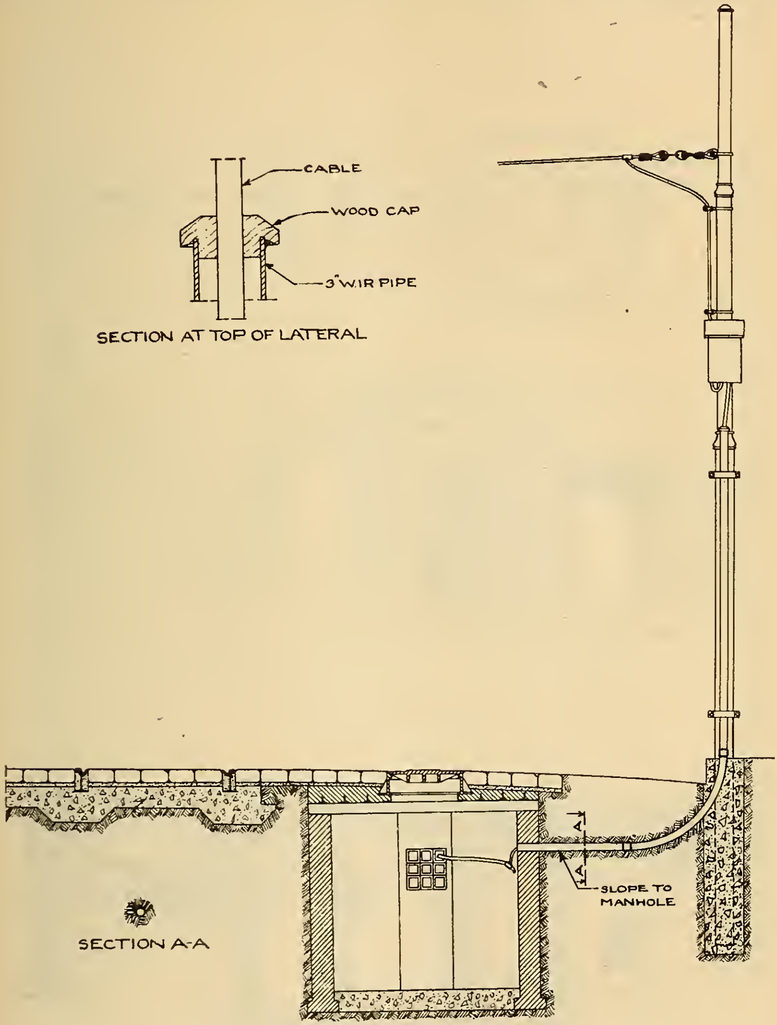


Fig. 17.—Manhole with Lateral Connection in Iron Pipe to the Iron Post.

Some comparative cost estimates are given below, which as will be noted, show that the costs do not vary widely. The totals are as follows:

	Iron Pipe Only. (Fig. 17)	*Sewer Pipe.* (Fig. 18)	*Tile Duct.* (Fig. 19)	*Iron Pipe and Fiber.* (Fig. 20)
Total cost, each.....	$ 13.49	$11.95	$11.25	$11.36
Percentages	100.	88.6	83.3	84.2

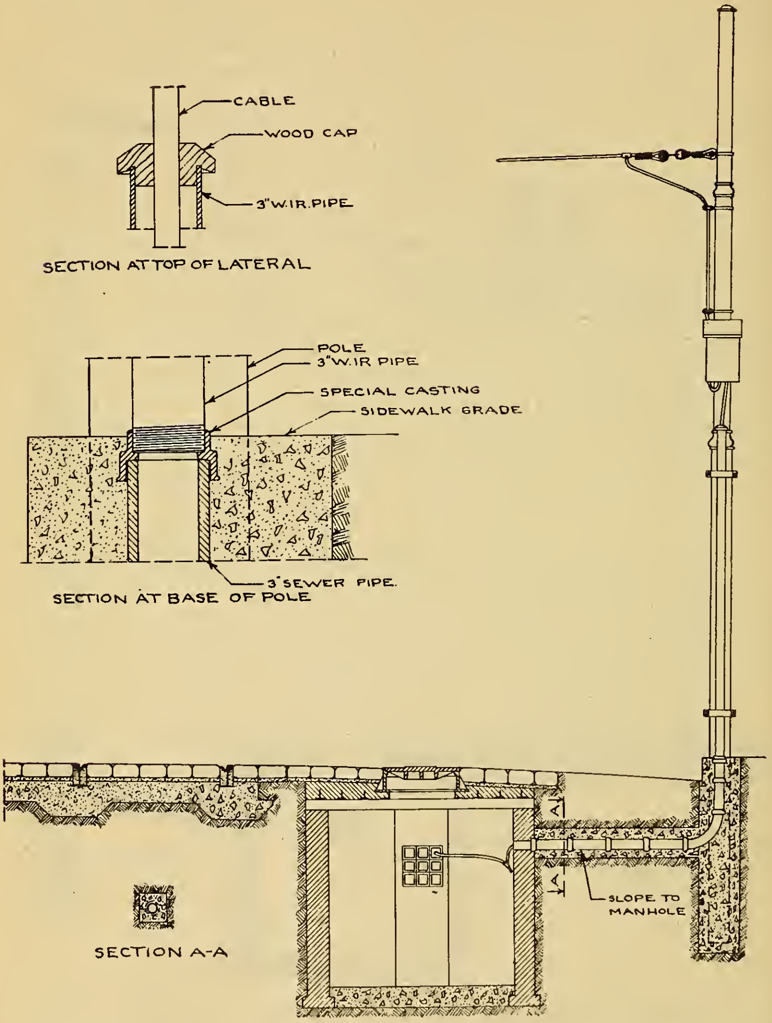


Fig. 18.—Manhole with 3-in. Sewer Pipe for Lateral to Iron Post.

Of these styles it will be observed that the cost of the insulated types are from 11.4 to 16.7% less than the uninsulated, and that the fiber costs only about 5% more than the other two insulated types and is 11.4% less than the iron pipe. If the fiber was stopped off at the beginning of the vertical iron pipe, as is done with the sewer pipe and tile duct, its cost would be about the same as these forms. It is believed that the fact that the insulation can be carried up the vertical run is very much in favor of the use of the fiber in combination with the iron pipe.

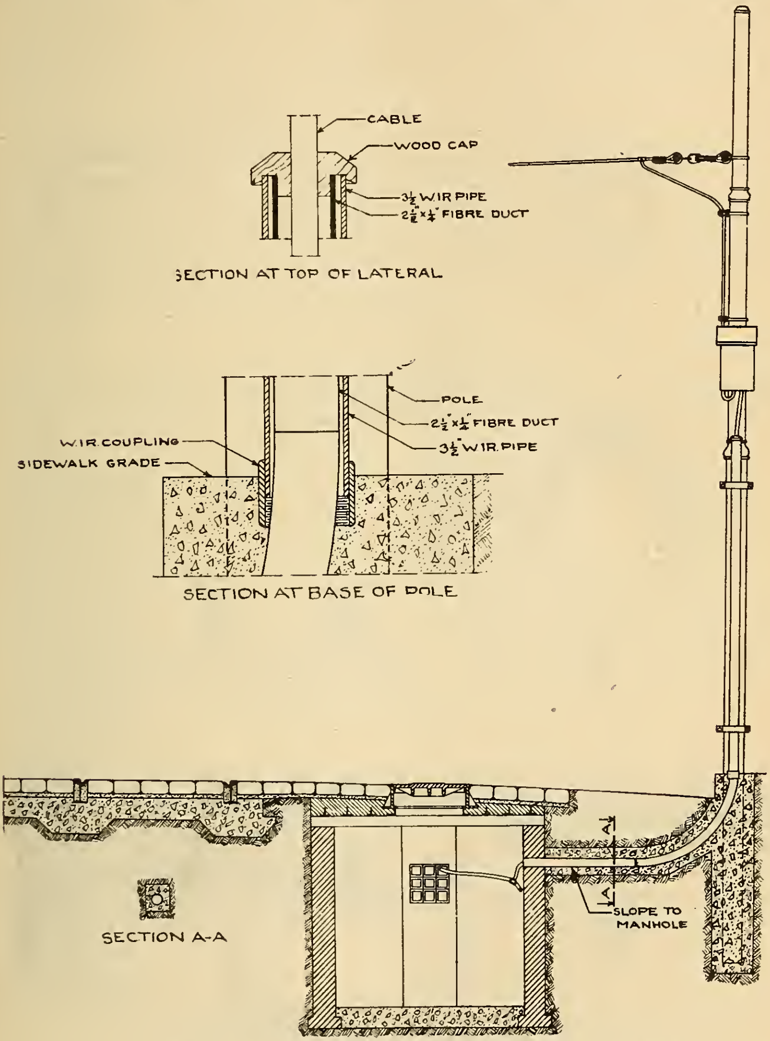


Fig. 19.—Manhole with Standard 3½-in. Duct for Lateral.

III. Manhole Fittings.

So far as the ideas of cable protection and isolation are concerned, the modifications thus far discussed apply more particularly to the ducts outside of the manholes. In the manholes two additional considerations are involved, viz: the joints in the cables and the matter of accessibility. The importance of the latter will depend upon the perfection of the cable joints and the frequency of cable troubles from other causes.

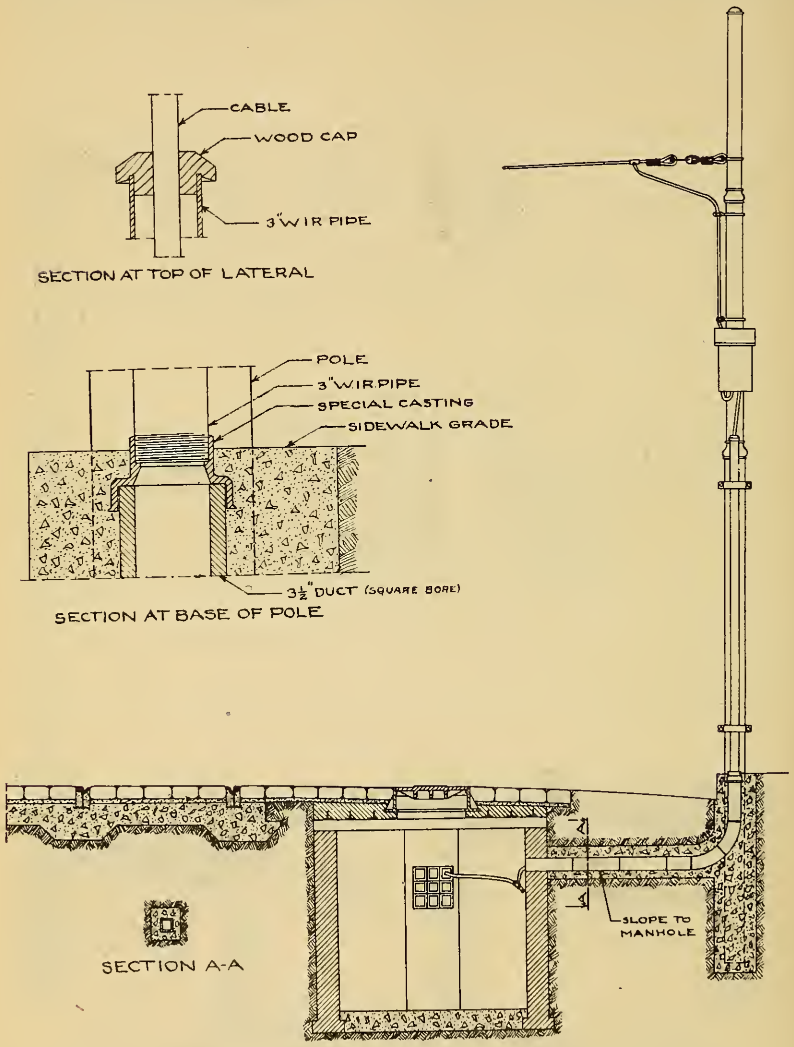


Fig. 20.—Fiber Duct Lateral with Iron Pipe Protection on Pole.

If cables are thoroughly isolated and protected so that when a burnout occurs only the defective cable is involved, then it is only a matter of securing access to one cable. The more perfect the protection and isolation of the cables the fewer will be the cables involved in a burnout, and hence the less will be the importance of accessibility. The degree of importance attached to preventative measures by the men in charge, will determine the weight to be given to the questions of accessibility and convenience as against isolation and protection.

Various wrappings of tapes composed of a mixture of asbestos and cotton, of steel and brass strips, and coverings of plastic materials have been used. Each may be particularly adapted to some set of conditions where their use would be perfectly satisfactory, but for the conditions here considered it is believed that in the manholes the same fireproof and arc-resisting materials should be used that are used in the ducts between manholes.

12. Fireproof Shelves.

Sheet steel has been used for shelves in manholes, but it has been found that if the metal is thick enough to give a reasonable degree of rigidity, the cutting and fitting is difficult and expensive. In case of a severe burnout the steel, because of its good conducting qualities and relatively low melting point, tends to spread and augment the trouble rather than localize it.

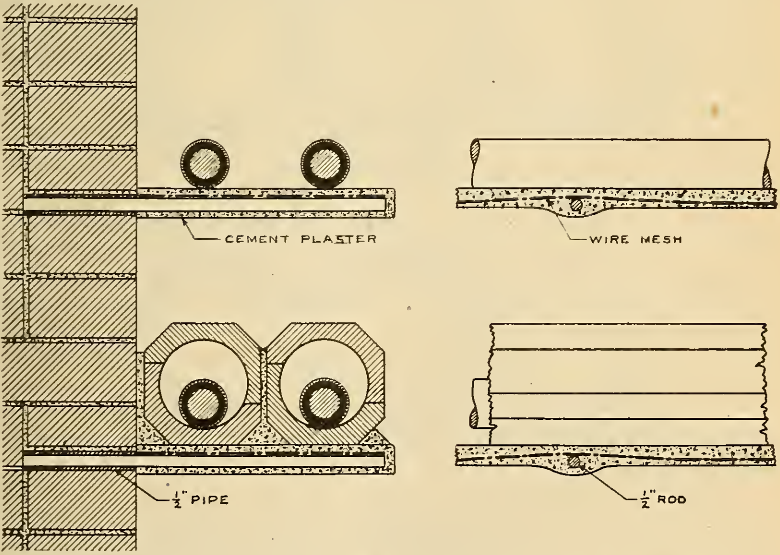


Fig. 21.—Concrete Shelves in Manholes Also Serving as Barriers. Lower Shelf Equipped with Split Duct.

The upper part of Fig. 21 shows a shelf construction that it is believed is less expensive, more flexible, and with the metal parts entirely covered with cement, so that it is a combined shelf and barrier. The wire mesh may be had in rolls and can be easily cut and fitted with a pair of ordinary snips, and any man who is at all familiar with the use of the trowel can, with a little plasterer's hair mixed into the cement mortar, readily lay these shelves in place. Cables are thus effectually separated into groups by a substantial horizontal barrier of fireproof material. Where only a small number of relatively unimportant cables are involved this construction gives a degree of isolation that is quite sufficient.

13. Split Duct.

For a larger group of more important cables, the split duct construction shown in the lower part of Fig. 22, in addition to the reinforced cement shelves, can be used advantageously. Split duct is made by scoring the walls of the duct as it is excluded from the presses, so that after being burned it can be shipped to the work in whole pieces and there broken into parts for use.

The four different forms of split duct, which are available for this style of construction, are shown: Fig. 22 is the original form, with joints opposite and in a straight line between the two cables. The cement joint, however carefully made, is certain to be more or less imperfect. So with this form the weakest points in the separating wall are placed immediately adjacent and on a line which is the shortest path between the two bores.

Figs. 23 and 24 are forms designed to overcome this objection, but the sharp corners and angles introduced are believed to be objectionable because of the increased breakage that would result when an attempt is made to separate the two half-sections for use.

Fig. 25, which, in point of time, was the first attempt to overcome the objections to the opposite joints of Fig. 22, has the straight scoring which facilitates separation, and its joints, when ducts are laid adjacent, are off-set about 1½ in. In the first lots manufactured some little difficulty was found in breaking the sections apart, but with closer attention to the dimensions of the scores this was corrected.

Short lengths and 45° and 90° bends can be secured so that almost any series of safe bends for a large cable can be covered with the split duct.

In an average manhole the cost of this construction over that of ordinary metal racks with, say, a double wrapping of asbestos tape, will amount to about $1.00 per cable per manhole, which, considered as an insurance premium, would be small if the average distance between manholes is 350 feet, and the value of cable and connected apparatus is $2.00 per foot.

IV. RECOMMENDATIONS.

For any new underground conduit construction in any large distribution system, the following recommendations are made for the consideration of the engineer in charge of designs, and for the man who will be in charge of the cables when they are placed in service:

1. Make absorption tests upon the ducts and include an absorption requirement in the duct specification.
2. Use square bore single duct for the standard construction.

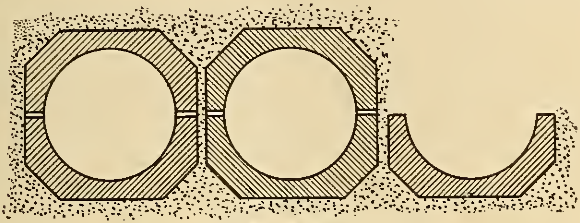


FIG. 22

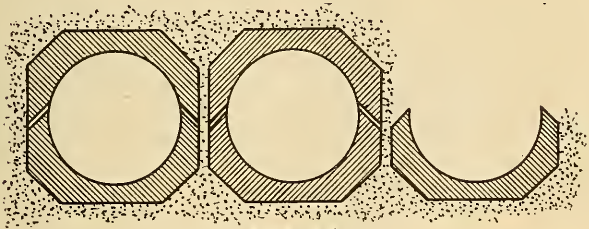


FIG. 23

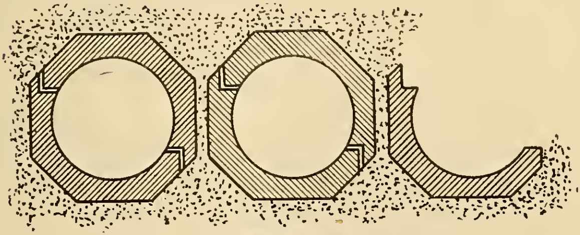


FIG. 24

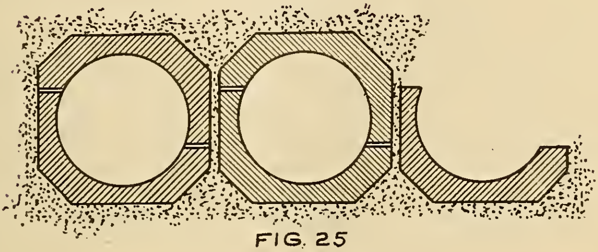


FIG. 25

Figs. 22-25.—Types of Vitrified Clay Split Ducts.

3. Enforce a rigid adherence to a definite plan of staggering the joints.

4. Have all voids between ducts, especially at corners, thoroughly filled with mortar and concrete.

5. Order all future duct with outside corners made on not greater than a quarter inch radius.

6. Install present form of duct in longitudinal tiers, separated by a substantial layer of concrete for important lines.

7. For extra important lines or high tension lines, install round bore duct with horizontal and vertical concrete separation.

8. Construct all lines of 16 ducts or more in the duplex form.

9. For laterals, use fiber protected with iron pipe on the vertical run up the pole, and protected with concrete at the bend and on the horizontal run.

10. In manholes, use reinforced cement shelf barriers for small groups of cables of minor importance. For larger groups of important cable use the split duct in addition to the shelves.

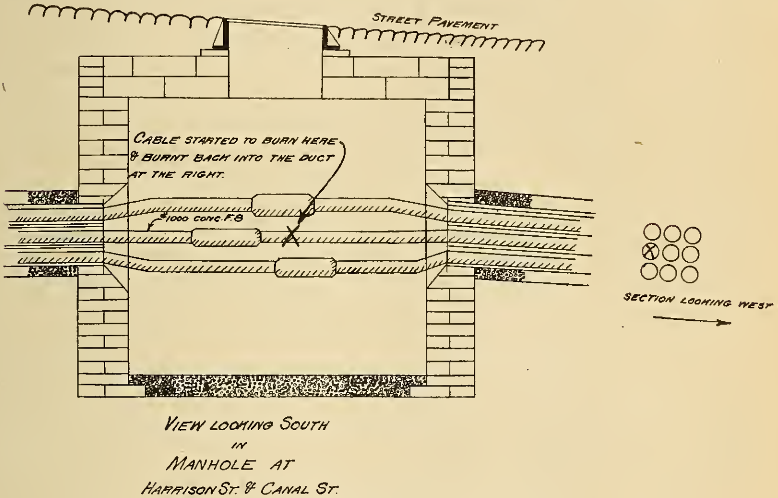
In this audience are men who have been connected with perhaps 80 or 90% of the conduit construction in this city, and naturally it was with some hestitation that I appeared before you this evening with a paper under the title given. I hope, however, that you will consider the paper in the light of suggestions made to bring out discussion, and I trust you will not hesitate to criticise any of the suggestions, especially the poor ones.

DISCUSSION.

Mr. D. W. Roper, M. W. S. E.: This paper on underground conduit construction is an interesting one and I agree heartily with Mr. Lake on a number of his statements, which contain some excellent new suggestions. There are, however, a number of his theories with which I disagree. The first of these is the statement that vitrified clay is the best non-conductor of heat and arc-resisting material that we have. Recently I endeavored to find some scientific data for comparing concrete with tile in specific heat, in heat conductivity, and in resistance to high temperatures.

The data which I found was not given in a form admitting of ready comparison, but the experiments forming the basis of the several articles indicated that concrete construction was a poorer heat-conducting material than vitrified tile.

The Commonwealth-Edison Co. had an experience in a burnout some time ago that illustrates this point very well. In Fig. 26 is shown three cables, on one side of the manhole, which occupied the three ducts in one vertical row on that side of the conduit. In the manhole, however, the cable was covered with split tile as mentioned by Mr. Lake. The duct material used in this conduit was of the variety known as stone pipe, which is all concrete except a small band of metal, like a napkin ring, which holds the two abutting ducts in alignment. The burnout apparently started immediately to the right of the joint, at a point inside of the split vitrified tile, and burned towards the right into the conduit. (There was no trouble whatever on any of these cables to the left of the joints.) The street had a perceptible grade downward to the right, and the conduit being approximately parallel to the surface of the street, had a sufficient grade so that the melted copper and lead from the burning of the cable in the duct ran along in the conduit beyond the burn. There was one large cable in each of the nine ducts in the conduit, and the cable which was the most badly injured, and which apparently was the cause of the trouble, was in the middle duct of the outer vertical row. When we were able to get into the manhole, we found that the cable ended at the point just to the right of the joint where the trouble had apparently started. The rest of the cable had disappeared except for some stalagmites of lead and copper in the bottom of the manhole. This was a 1,000,000 c. m. concentric cable, carrying low tension direct current at approximately 230 volts. We saw that all of the cables in this part of the manhole, as well as those on the side of the manhole opposite from that shown in the picture, had been badly burned by the action of the arcs from the several cables. Two similar concentric cables on the other side of the manhole had also burned in two, but careful consideration of all of the facts in the case leads us to believe that the cable indicated in the drawing was the one on which the trouble started; it was without any doubt the one which was the most badly injured. In the high tension cables in the ducts immediately above and immediately below this concentric cable, all of the lead had melted and the paper insulation was so badly burned that it could be easily knocked off with a stick. These latter cables were high tension


STREET PAVEMENT
CABLE STARTED TO BURN HERE & BURNT BACK INTO THE DUCT AT THE RIGHT.
#1000 CONC. F.B
SECTION LOOKING WEST
VIEW LOOKING SOUTH IN MANHOLE AT HARRISON ST. & CANAL ST.

Burnout of Cable in Manhole.

cables protected by automatic switches, and therefore, they could not maintain an arc for more than one second. The condition of the high tension cables indicated that all of the damage had been caused by the arc from the low tension cables, so that the heat which melted the lead from the high tension cables and charred their paper insulation, was conducted through two layers of split vitrified tile. Most of the split tile protecting the cables was still in position when we entered the manhole, and we could not accurately determine the condition of the cables until these tile coverings had been removed. As there were nine cables which had to be replaced, and their average cost was something like the figure which Mr. Lake gave in the paper, namely, $1.25 or $1.50 per foot, we were much interested to know whether and how far the cables were injured in the conduit; that is, to determine whether we would have to replace the entire length of cable to the next manhole, or whether the cables were only burned back into the duct a few inches, so that it would be sufficient to enlarge the manhole, cut off the cables beyond the point where they had been injured, and splice on new sections a few feet in length. To settle this point we immediately made an excavation alongside of the manhole and exposed the 10 feet of conduit adjacent to the manhole. At the time that we had the conduit exposed, the manhole was still so hot that we were unable to do any work on the cables, and as the burned ends of the cables were hanging down in an irregular manner we had not noted that there was one cable for each of the nine ducts in this conduit section. As soon as the conduit was exposed, the foreman in charge of the work, who was a man of many years experience in the business, got down into the trench and personally broke into the concrete ducts forming the conduit, so as to determine the extent of injury to the cables. The top duct of the outer vertical row was first broken into with a hammer, and the cable therein was found to be uninjured in any way except for about an inch immediately adjacent to the manhole. The foreman then broke out the next duct, and finding nothing in it, put his hand into the duct, running it back and forth to feel the condition of the duct; upon doing so he immediately said: "That duct is vacant, there is no cable in that duct at all." He then broke away the next duct in the lower row and found it was occupied by a cable which was in excellent condition. To check the foreman's statement that the middle duct was vacant, men were sent to the next manhole and found that there was a 1,000,000 c. m. concentric cable in the duct which had been declared vacant. We thereupon made a more careful examination of the pieces of the concrete pipe which had been thrown out of the trench, and broke off more pieces of the so-called vacant duct. We found by this examination that the concrete, although almost as smooth on the inside as new concrete pipe, showed perceptible signs of burning for nearly ¼ in., and that the surface material was inert, that is, friable and easily removed, like lime. The remaining portion of the concrete pipe, comprising about three-quarters of the total thickness of the pipe, appeared to be just as good and strong as it ever had been. We have here, therefore, a direct comparison between the arc-resisting and heat-conducting properties of the vitrified clay tile around the cables in the manhole, and the concrete pipe surrounding the cables in the conduit. It is the same cable, and the current in the arc was fed from the same source throughout the trouble. The cable burned for about 25 feet into the conduit before is was disconnected, and although there was considerable flame in the manhole, due to the burning of the gases from the resinous material in the paper insulated cable, the arc was at a considerably higher temperature than this gaseous flame, and the heat from the arc was conducted through two layers of tile in the manhole so as to melt the lead off of the cables in the adjacent ducts, while it failed to injure in any way the lead or the insulation of the cable in the concrete pipe of the conduit. The tile conduit in the manhole also showed, on its interior surface, greater signs of injury from the direct action of the arc than did the concrete pipe in the conduit.

Mr. Lake spoke of the desirability of getting vitrified clay which is free from moisture, because of the difficulties which would be caused by an arc or other sources of heat in the duct or in the conduit construction. This freedom from moisture is also desirable from the opposite point of view—that is, in the case of the freezing of the ground. We had a case some years ago where the ducts were laid, as most of our conduits are, within freezing depth—that is 30 inches more or less, of the surface of the street—and these ducts had a high percentage of absorption. Some years later, on account of the city building a sewer along that street, we had to move several blocks of that conduit, which gave an excellent chance to examine it. We found that this particular conduit was so badly broken that it could not be handled; there were a series of fractures running all through the tile like crackle ware. It apparently had been ruptured by freezing, and although it had not so broken that it collapsed and filled up the hole, it showed that the structure was considerably weakened and might have caused trouble later.

A section is shown in Fig. 13 with the ducts laid in horizontal rows separated by an inch of concrete, which the speaker called a single duct laid in tiers. It is very difficult to secure uniform thickness in spreading a single layer of concrete, and to keep the ducts in alignment after they are laid. After the trench is excavated, three inches of concrete is laid on the bottom, then a layer of ducts, then one inch of concrete and another layer of ducts; but the workmen will walk on this latter layer of tile resting on an inch of concrete which has not set, with apparently nothing to hold the ducts in alignment except gravity and the friction on the concrete. The result is that with that kind of construction, instead of getting the expected 3½ in. of opening, it is found that, in attempting to pull a 3 in. mandrel through, it cannot be done; in fact, it is sometimes difficult to get a 2½ in. mandrel through. The question of alignment is one of the hardest problems in the single duct tile construction, and our experience is that we have less difficulty drawing our cables into 3¼ in. round section concrete pipe, which is in more accurate alignment, than we have in 3½ in. square bore vitrified tile.

Occasionally we have had difficulty in drawing cables into the tile ducts, and the foremen have brought sections of such cables into the office which looked as if they had a square section; that is, the ducts would be offset in one place so that the cable would be squeezed and flattened, and in another place the cable would twist or the alignment would be offset in the other direction, resulting in a section that looks like a square cable with rounded corners—not 3½ in. square, but something much smaller than that—2½ in. or thereabouts.

The statement was also made that the square section offers less resistance when two or more cables are being drawn in. That is the reverse of our experience. The men on the ground who have actual charge of installing these cables say that the large cables, from 2 in. to 2¾ in., are drawn into the ducts with apparently less friction with the square section than with the round section, their theory being that the arc of contact with the cable and the duct is less when the cable rests on a flat surface than when it rests on the inside of a cylindrical surface. I am speaking in both cases, of course, of conduit section in which one meets with no difficulty like the offset ducts that I spoke about a few minutes ago. Where we have two or three or four single cables pulled into one duct, however, the cables apparently assemble so that they fill the larger portion of the duct, but they become wedged in there, and then as the pulling rope turns—and it always does unwind somewhat as the strain is applied—that twists the grip which is fastened to the cable and twists the cable in the duct. When this twisting action occurs, these cables have to move on each other and assume a new relation with respect to each other. That does not occur where we have a round duct contsruction, and where the cables can twist in the duct and always hold the same position with respect to each other.

In the illustrations showing the laterals there were several suggestions, one of which included a fiber duct or pipe, surrounded by iron pipe. As I read the picture, however, it appeared that these lined iron pipes were all intended for small cables like the single comparatively small cable that was shown in the laterals. That appears to be an excellent idea, but I should be glad to see how to apply this idea practically to a case where it is desired to pull four cables into the lateral, and the cables nearly fill a 3 in. round pipe. That means that you have to maintain a 3 or 3½ in. section throughout the length of the lateral instead of having it 2½ or 2¼ in. through part of the lateral.

Among the suggestions was one which included a square conduit for certain kinds of cable, and a round bore for certain varieties of cable. The difficulty I have found in laying out conduit lines is to tell just what particular duct in the conduit is going to be used for high tension, and which for low tension or some other variety. It is very difficult indeed for us to tell in which section of the city our growth is going to be, where the next large customer is to be located, and what kind of current he will want. We even find considerable difficulty in determining, with any degree of accuracy, the size of conduits—that is, the number of ducts that we should install in some particular street. I remember one case where we did not have a conduit within several miles, but as one of our friends was building one and asked us to build a joint conduit, we took a chance and asked him to build three ducts for us, although we had no conduit within two miles of it. Within three years we had to install four additional conduits in that street, so that we had seven ducts where we thought three were enough to last us five or ten years.

The speaker, in referring to single duct tile, did not bring out one of its good points, which is one of its most valuable assets for conduit work, and that is the ease with which a tile conduit line can be broken out and repaired. We frequently have a case of trouble, either real or fancied, where we have to, or do, dig up the conduit line to repair or to examine the cables. In come cases we have to break out the conduit to allow the installation of a water pipe or a sewer or something of that sort. With some of the multiple duct sections, the replacement is very difficult and almost impossible without first removing the cables. With the single duct vitrified tile, however, you can, by the aid of split tile, lay the same identical conduit section around the cables which are already in the conduit, and then lay the standard single duct straight tile for the rest of the ducts.

Prof. Woodworth: Are we to infer that in your opinion concrete tile has a better heat-resisting value than the regular vitrified tile?

Mr. Roper: Yes, sir.

Mr. W. B. Jackson, M. W. S. E.*:* I wish to ask Mr. Roper if it is the custom of his company to carry out three or more cables from a single lateral? He spoke of that as being one objection to the lateral shown by Mr. Lake.

Mr. Roper: We frequently install several cables in one lateral; they are comparatively small, however; for instance, in our low tension work we install three No. 6, three No. 0, or three No. 0000 cables in one lateral. If those three cables occupy one duct in the conduit, we continue the whole construction and put the three cables in one lateral pipe up the pole. In our sixty cycle work we follow the same practice, and install as many as four No. 6 or four No. 0 cables in one lateral pipe up the pole, which is the same construction that we have in the conduit.

Prof. Woodworth: Mr. Baird, of the McRoy Company, is asked for his opinion as a representative of a conduit company.

Mr. C. A. Baird, (McRoy Clay Works): I have listened with a great deal of interest to the various talks, and there seems to be a difference of opinion on the part of engineers. I think I can safely say that the manufacturers of clay conduits are all of one opinion, that is, that of course they manufacture the best conduit there is.

Referring to the point which Mr. Roper made in showing the manhole with the burnout. Would the conditions have been changed if the concrete had been used in the manhole to encase the joint of the cable and the tile leading back underground? That is, would not the same result have been obtained?

Mr. Roper: Replying directly to Mr. Baird's question, I will state that, judging from our experience in similar cases of burnouts on concentric cable connected to our low tension system, if the duct material in the conduit had been vitrified clay tile, this tile would have been partly melted by the arc, and the cables in the adjacent ducts would have been quite appreciably injured. We have had several cases of trouble of this kind where the burning of a concentric cable in a tile conduit has melted the tile and injured cables in adjacent ducts.

Mr. F .W. Darling (Clay Product Co.): I appreciate very much the invitation given me to come here tonight. Mr. Lake mentioned the round bore single clay conduit. It is true that in the manufacture of conduit the round single ducts require considerably less care. Suppose that we have rejections, that is, cull out in the manufacture of square single tile, 10% of them; in the round single ducts we can cut the amount down to almost 2%. If there is that difference in the manufacture of the tile, there would naturally be that difference in the cost of the two. This is probably due to the fact that in burning the round single duct, having a sort of arch construction although of clay, it does not give way under the strain of manufacture and burning as the broad side of the square duct does. Also, it is reinforced by the extra thicknesses of clay on several corners instead of having a flat side and equally thick corners.

In regard to the voids in connection with the square duct. After Mr. Lake sent us that letter asking for information relative to manufacturing the square tile with a very small radius on the outside corners, we attempted to make some, using an old die and filing out the corners. We found that such tile could be easily made, but that if the clay is run stiff and thick, requiring but a short time in the dry room and thus reducing the cost, it roughs up or scales on the corners. That does not injure the tile, however; the outside is simply roughened up, with a little peeling and scaling. The inside remains perfectly smooth. Of course, the inspectors might infer that those cracks went through.

A well vitrified clay conduit, in its manufacture, is burned to a temperature of approximately 3,000°. It is supposed to stand a temperature of about 4,000° before giving way. Under usual and ordinary circumstances, cement products cannot stand a temperature of over 1,800° without having the lime salts broken up and dissipated, reducing the cement mass to a condition about as friable as soft plaster. With this in mind, it seems hardly fair to accept the single instance which Mr. Roper mentioned as a proof of the test. It seems as if we ought to be able to find another reason for the destruction of the cables in the manhole while they maintained their contact in the duct lines. It occurs to me that an explanation may be found from the fact that the duct lines had a gradient up to the point where the burnout occurred. This being true, the instant the temperature was raised at the point of burnout a draft would be generated from the conduit line towards the manhole. As the burnout extended along the cable, the path of the draft being determined previously, this current of cool air would doubtless increase considerably and carry the heat out of the duct, acting as a flue. That this was true to a certain extent is shown by the fact that the residue from the burnout was found in the manhole, and a further proof would be that adjacent cables in the manhole were burned inside of the clay conduit by the prolonged temperature thus maintained. I am, in fact, surprised that the clay conduit in the manholes did not give way under the temperature thus produced. It is, of course, admittedly important, with our present knowledge, to get a substance for conduit which will be practical, and yet withstand the terrific temperature produced by a burnout, but the tests which we have made, comparing vitrified clay conduit with cement and fiber products, show conclusively that the clay conduit will withstand temperatures varying from 1,000° to 2,000° higher than either of the other substances.

Mr. George B. Springer, M. W. S. E.: I do not want to bring Mr. Lake to tears, but he spoke of laying conduit in tiers, that is, separating it by one inch of concrete. While 1c a duct foot does not seem to be a very large figure for one duct foot, it occurred to me, when I looked at some of his sections there, that when you come to install say 2,000,000 duct feet it is a matter of $20,000, and I have some doubts as to whether the excess cable trouble which we might experience in a year, directly traceable to the voids in laying conduit, would approximate anything like $20,000. Therefore I think that one inch of concrete between the ducts would not be advisable from the standpoint of economy, and having a structure which is good enough for the purpose. In other words, I do not think that the expenditure would be justified.

Mr. Lake: It should be remembered, in considering these suggested improvements, that some of us are looking at the problem from the standpoint of railway distribution, and others from the standpoint of the Commonwealth-Edison, large lighting and power company. This may account for some of the differences of opinion which have been expressed.

I will ask Mr. Roper if the burnout referred to is what is called a "slow burn" or one which started from a short circuit, and was sudden and vicious in its action?

Mr. Roper: As near as I can recall the matter, it took something like half an hour to burn the 25 or 30 feet of cable, or it may have been 45 minutes before the cable was entirely disconnected. (I might say that concentric cable burning that way does not burn at all rapidly.) I watched the cable burning while the men disconnected it from the underground mains in another manhole; it burns much like a fuse would burn, with a fairly continuous arc, illuminated now and then with a burst of flame.

Mr. Lake: Was there a steel shelf in the manhole?

Mr. Roper: Yes, there was.

Mr. Lake: Just one more question, Mr. Roper—were the cement ducts separated by concrete?

Mr. Roper: There was an inch of concrete between ducts.

Mr. Lake: One inch of concrete on all sides? That is, the ducts were really laid in horizontal tiers?

Mr. Roper: Yes.

Mr. Lake: The matter of concentric cable burnouts is something that is unfamiliar to those of us who are interested in street railway distribution here in Chicago. I am inclined to agree, however, with Mr. Baird, that the results might have been the same if the burnout had occurred in a vitrified clay duct. At any rate, the one inch of concrete between the cement pipe is certainly a desirable feature.

The matter of laterals which we use in street railroad work and the size of cable is confined almost entirely to 100,000 and 500,000 c. m., ordinarily; 350,000 c. m. is also largely used. Those are the three sizes of single cable which would be used in the construction of laterals. It is possible, however, to secure fiber in the larger sizes, and of course, possible to secure the iron pipe to protect the fiber up the pole of any size which might be desired. Fiber can be obtained of any size up to 8 or 12 inches, but I believe the latter is the limit that is manufactured at the present time. Four inch pipe and its lining would be thoroughly practicable, and the lining would not have to be very thick.

PHASES IN THE DEVELOPMENT OF THE STREET RAILWAYS OF CHICACO

BION J. ARNOLD, H. B. FLEMING AND GEORGE WESTON.
MEMBERS W. S. E.

Presented at a Joint Meeting of the Electric Section, W.S.E. and of the Chicago Branch, A.I.E.E.—May 28, 1909.

Mr. W. L. Abbott, M.W.S.E. (Chairman): We are indeed to be congratulated in having been able to make arrangements for the program which we have tonight. The traction problem of Chicago has been one of paramount interest here for years, and it was not until comparatively recently that this community was able to free itself of entanglements so that it could go about the reconstruction of the street railway systems. Having so cleared itself, it determined to have the best traction systems which it is possible to construct. The city, with the traction companies, proceeded to organize a Board, to take up and solve these questions as they should be solved, and then reconstruct the traction systems according to the plans which they had designed.

It is our privilege to listen to these engineers who have this work in charge, engineers whom we all know are the peers of any in the country in this line of work. The Board of Supervising Engineers is presided over by a gentleman who is a Past President of the Western Society of Engineers, and also a Past President of the American Institute of Electrical Engineers, and being the Chief Engineer of the Board it is very appropriate that he should speak here tonight and open this discussion.

I have great pleasure in introducing Mr. Bion J. Arnold, Chairman and Chief Engineer of the Board of Supervising Engineers, Chicago Traction.

Mr. Bion J. Arnold, M.W.S.E.: My mission tonight, as I take it, is to outline in a general way the steps which led up to the adoption of the present ordinances and to give a general statement of the way in which the work of the Board of Supervising Engineers is conducted, leaving to other members of the board to follow and explain to you more explicitly what we are really doing.

Perhaps, while you may have read in the past about our traction problem and do read in the papers regarding traction at the present time, you may not have read the papers during the formative period of this traction question or prior to the time when the present ordinances began to be discussed, so that it may be well to go back a little into the history of the traction situation prior to the adoption of the present ordinances. This traction question had been a question in this city for about ten years prior to the adoption of the present ordinances on February 11, 1907. During these preceding ten years, various differences of opinion arose between the citizens and the traction companies, as is often the case in other cities. Most of these differences arose through misunderstandings, and it was only when they were thoroughly discussed—threshed out, as it were, before the public and before the authorities representing the city—that they were finally understood and a basis agreed upon which forms the present plan under which we are now reconstructing the properties. These ordinances were shaped only after many months, we might say years, of work on the part of the legislators of the city and of engineers representing the city, in determining the value of the present properties and in assisting in outlining the present ordinances. As a step precedent to the establishment of the present ordinances, it was deemed by the authorities of the city necessary to value the properties of the present street railway companies, and a valuation commission was organized in 1906 to value the properties. This was called the Traction Valuation Commission, and consisted of three men appointed by the city. These men spent several months examining the properties, and finally submitted to the City Council a report which fixed the valuation of the properties at about $47,000,000, exclusive of the pavement, or about $52,000,000 including the pavement. The reason that the valuation was given in this manner was due to the fact that there was a legal question involved, which could not be determined without litigation. The attorneys for the railway companies contended that they were entitled to credit for the pavement, while the attorneys for the city contended that the companies were not entitled to credit for this pavement. There was no way for the Valuation Commission to determine this question; consequently it submitted its figures both ways, in order that the City Council, through its Transportation Commitee, could determine which figure it wanted to take or whether to make an average of these figures, which was finally done. The result was that the Transportation Committee of the City Council finally agreed upon an even figure of $50,000,000 as a fair valuation for the property of the two railway companies—the Chicago City Railway Company and the then Chicago Union Traction Company, now the Chicago Railways Company. Of this sum, $21,000,000 was allotted to the Chicago City Railway Company, and $29,000,000 to the Chicago Railways Company, and those figures were accepted by the railways and formed the nucleus of the present valuation of the properties.

The ordinances provide that the properties shall be reconstructed under the direction of a Board of Supervising Engineers, and in accordance with plans prepared and approved by that Board. The companies are to be credited with this $50,000,000 and with all additional money that is put into the properties in accordance with the plans which must meet with the approval of the Board. Thus the city, in case it ever should get ready to purchase, knows the exact price of the properties at the time of the purchase, as no money is credited to capital account without it is certified to by the Board, the certificates being filed monthly with the City Comptroller. There is thus always a record in the City Hall of the exact amount of money that has gone into the properties; the work of this Board, among other things, is to certify, from month to month, the amount of work done during the previous month.

These ordinances provide in general as follows: the railway companies agree to completely rehabilitate the properties, and furnish sufficient money to accomplish this purpose in accordance with the plans which this Board prepares, there being no limit to the amount of money that the railway companies are required to furnish, leaving that question to the judgment of the Board of Engineers.

This Board of Engineers consist of four men, two of whom represent the companies, one represents the city, and the fourth man represents both parties. When any question arises which affects one company, that company has a full vote through its representative on the Board, the city has one full vote, and the third man has the deciding vote between the two, in case of a difference of opinion. I am glad to say that up to the present time there have been very few final differences, almost all questions having been decided by a practically unanimous vote. In case a question arises which involves the interests of *both* the railway companies, then the representatives of the railway companies upon the Board have a half vote each. So that there is always one railway vote, one city vote, and one independent vote. It may be cast with the railway company or it may be cast with the city; it depends upon what this third man on the Board thinks of the question. I want to make it clear, because the Board practically consists of three men, when it affects the interests of any particular company, but when the two interests are affected, then there are four men that vote, but the two railroad men then constitute one vote. That plan was provided for in the ordinance in order that there might always be an odd vote on the Board.

Under the ordinances, the companies are required to largely reconstruct their systems within a certain three years "rehabilitation period." This rehabilitation of the properties has cost close to $30,000,000 in the last two years. We have the remainder of this season for work with the Chicago City Railway Company, during which it will spend probably $2,000,000. The Chicago Railways Company has yet two years for its improvements so that there will probably be put into the properties, before we get through, somewhere between $35,000,000 and $40,000,000. We hope to get through within the latter figure, but we are not sure, as it depends upon whether we build power houses or not.

The ordinances provide that the railway companies shall receive a profit on this reconstruction work of 10% over and above the actual cost to the company. In addition thereto, there is an additional 5% allowed for securing the money, that being the ordinary brokerage that it costs to secure money, taking into consideration the discount on the bonds and other incidental expenses toward securing it. So that the companies receive 15% over and above the actual cash used in the rehabilitation work, their net profit being 10%. They are furthermore required to set aside or spend upon the properties after they are once reconstructed, 6% of the gross receipts for maintenance or repairs. That means ordinary up-keep, such as replacing small parts, brake shoes, wheels, and things of that character. In addition to that, they are required to set aside 8% of the gross receipts monthly, into a special fund, deposited in banks designated by the city, and approved by the Board, which funds remains in the bank unless it be drawn upon to replace principal parts of the property. For instance, if it becomes necessary to replace an old car with a new car, this fund is drawn upon for an amount equivalent to the value of the old car and the difference between the cost of the new car and the cost of the old car is charged to capital account. The old car is sold; the amount of salvage from the old car is deducted from capital account. Thus capital account is only increased to the extent of the cost of the new car over the old car, less the salvage on the old car. That is why this fund is called the renewal and depreciation fund. The ordinances were framed upon the theory that the city should be able to purchase the properties at any time, upon giving six months' notice to the railway companies of its desire to do so. That is, the city can purchase on the first of February of any year, after having previously given six months' notice of its desire to purchase. The price that the city would have to pay would be known by virtue of the valuation previously fixed, viz., $50,000,000, plus the sum of the certificates issued by the Board up to the time of purchase. Now in order that the city would be insured of a first class railroad system, or enough cash somewhere to put it in first class shape, this renewal fund was established. After the rehabilitation work is completed, it is expected that the railway will be maintained to as high a point of efficiency and maintenance as a railroad can be maintained. We have assumed, from the best information that we could gather, from the experience of the members of the Board, and from other engineers with whom we have conferred, that it would be possible to maintain a railroad at about 85% of its first cost. Before any large railroad system is finished, part of it is worn out, consequently you can not maintain it at 100% of its original cost, but you can probably maintain it at about 85%, and this renewal fund is intended to maintain the property up to that point all the time, and that 85% is considered under the ordinance as 100% good, that being the highest point at which it is expected that you can ever maintain this property. But suppose at the time of purchase by the city that the railroad companies have not maintained the properties up to this 85%, then the difference between that value and the value at which they have maintained it, will be found in cash in this fund, which will be taken over by the city at the time of the purchase. Thus the city acquires a railroad in first class condition, or it acquires a railroad in poor condition but with enough cash on hand to put it in first class condition. This is a very wise provision in the ordinance, although there has been no disposition shown as yet, not to put the money into the roads and maintain them properly, and probably will not be.

The ordinances provide that out of the gross receipts of the railway companies, first shall come the operating expenses of the companies; then will come this renewal fund of 8 %; the operating expenses including the 6% fund previously mentioned. After the operating expenses and these funds have been provided for, the companies receive 5% upon the amount of cash invested in the properties at the time of consideration, as evidenced by the Board's certification. After this 5% has been deducted, there remains a net balance of *something*. That net balance is divided between the companies and the city in the proportion of 55% to the city and 45% to the companies. This feature of the ordinances naturally requires some supervision on the part of the city or somebody, in order that the public may be assured that the city is receiving its proper proportion of the net profits. Consequently, the power of supervision of the books of the companies is placed with this Board of Supervising Engineers. The result is that the Board has a large auditing staff, which is constantly in touch with the books of the company; in fact it has auditors in the offices of each of the companies, supervising the books, or, to see that the books are kept in accordance with the forms which have been originated by the Board and approved by the City Comptroller. Our auditors pass from one company to the other and check up monthly all expenditures upon which to base our certificates. During the reconstruction period, these certificates are not only based upon the books of the company but also upon the reports of the Assistant Engineers, working under the Chief Engineer of the work, of which Mr. Weston will tell you later, as he is the Assistant Chief Engineer and has charge of that part of the work. The Assistant Engineers are inspecting the work all over, simultaneously with the auditors' examination of the companies' books. Each set of men send reports into the office and the heads of the departments make up their reports to a certain point, independently of each other. Then the reports are compared and if there is no discrepancy between the engineers' report and the auditors' report, they are assumed to be correct, but if there is a discrepancy, then the thing is analyzed carefully and made to harmonize before the certificate is finally passed by the Board and submitted to the City Comptroller. Thus you see we have two independent sources of assuring ourselves of accuracy; first, the auditing department; second, the engineering department; and we feel that the work is thoroughly and carefully done, and that it is accurate, though of course some minor mistakes may creep in from time to time. But there is always a chance for correction, as we have sixty days to correct any certificate given. The result is we catch the error, if any, and correct it in a correcting certificate, and we believe that the records of the Board will be found sound by any one up to the present time, and we hope they will so continue.

Chairman Abbott: Those people who live in that part of Chicago which they are pleased to call the residence part of the city, the South Side, have always attributed not a little of the advantages of their section of the city to the superb street car service which has always been furnished them. When the cable was finally hauled out of the trench on its last round and everything was replaced by electric cars, the system which had theretofore been satisfactory became even more so. Mr. Harry B. Fleming, who has had responsible charge of the work of directing the engineering of the City Railway and who is also a member of the Board of Supervising Engineers, will next address you.

Mr. H. B. Fleming, M.W.S.E.: When requested to talk informally on certain phases in the development of the street railway systems of this city, I hesitated to accept the invitation, owing to the fact that the work covered such a broad field that it was difficult to decide on a subject which could be covered in the short space of time allowed and in a manner to prove of interest.

After consideration, I have selected the subject of

STREET RAILWAY CARHOUSE DESIGN AND OPERATION,

and I can only hope at the present time to call your attention to certain phases of this subject which are new and which I think will be of interest.

LOCATION: In selecting a location for a carhouse, the points to be considered are:

1. Provision for future requirements.
2. Convenience and economy of operation, i. e.—minimizing of dead mileage and maintenance.
3. Fire Risk—location with reference to other buildings.
4. Economy of Construction.
5. Facilities for drainage and sewerage, especially if pits are used.
6. Room for proper layout of tracks and extensions.

DESIGN: The Board of Supervising Engineers in considering the question of Carhouse design reached the following conclusions:

1. All carhouses that were to be permanent should be divided into bays or sections so as to reduce to a minimum the loss, in case of fire.
2. New carhouses to be built should also be divided into bays or sections and should be of fire-proof construction.
3. Where any old carhouses are to be remodeled in such a manner as to become a permanent structure involving the expenditure of considerable money, such buildings should be fire-proof.

4. Where it is necessary to remodel old carhouses, in order to accommodate the large modern cars temporarily and which would probably be abandoned in the near future; such modifications should be made with as little expense as would make them reasonably safe for the storage of property contained in them and that they should be abandoned and new fire-proof carhouses built in their place, at the proper time, at the same or more desirable locations.

5. Wherever conditions will permit, the carhouses are to be of the double-ended type.

The latest approved design of carhouses conforms with the above general requirements and I wish to call your attention to various features in connection with the same.

ACCOMMODATIONS FOR TRAINMEN AND CARHOUSE EMPLOYES: Ample accommodations have been provided for the office of the Division Superintendents, Clerks and Trainmen; in addition, a Club Room, Coat Room and Reading Room is furnished for the use of the employes assigned to duty at the Division of which the carhouse in question is the headquarters. The club room is furnished with pool and billiard tables, chess and card tables and a small amount of gymnasium apparatus and a stage. These rooms are open to employes at all times and they are given the privilege of holding various entertainments in them. A small library is kept in sectional book cases along the walls of the reading room and on the tables are current issues of daily papers and some of the technical journals.

Special attention has been paid to providing toilet facilities for all of the carhouse employes and in addition the repairmen are provided with locker rooms and lunch rooms.

CAR STORAGE SECTIONS: Each bay or section is independent of all others and all openings between sections are provided with double automatic steel fire doors. Each bay is approximately 490 ft. long and 38 ft. wide and contain three (3) tracks, with a capacity of thirty (30) standard double truck cars.

Each track is divided into three (3) sections; the middle section being pitted, so as to permit of ready inspection and repair of the trucks, motors and car equipment suspended underneath the body.

The fire-walls of each bay are of brick, 12 in. thick, spanned by re-inforced concrete girders spaced 16 ft. centers and 18 ft. in the clear and covered with a re-inforced concrete slab 4½ in. thick, cast in one piece over the entire roof. The middle eight ft. section of the roof of each bay, except at the end panels, is covered with fire-proof sky lights for lighting and ventilation. The ends of each bay are provided with galvanized steel rolling doors.

The tracks in the bays are connected with the main line in the street by curves at each end, or in other words the carhouse is of the double ended type, so that the cars can come in at one end, be washed and fumigated, passed over the pits, inspected and repaired, and thence moved on to the other end of the carhouse ready to go in service again, without any switching or reverse movement after the process is once started.

REPAIR SECTION: Every carhouse is provided with one section which is known as the *repair section,* where special provisions have been made and special machinery installed for the economical handling and repairing of cars.

I desire to call your attention, at this time, to the overhead travelling cranes, by the use of which we are enabled to shift our standard double truck car bodies from one pair of trucks to another pair in less than three minutes. These cranes are also very useful in the truck repair section. In addition to the above, each repair section is provided with the following tools:

1 motor driven lathe.

1 motor driven drill.

1 motor driven emery stone with 48 in. grindstone.

1 portable beam for swinging armatures into lathe with triplex chain blocks.

Assortment of drills, and of wrenches.

1 mandrel and 40 in. forge.

2 vises.

1 carpenter bench.

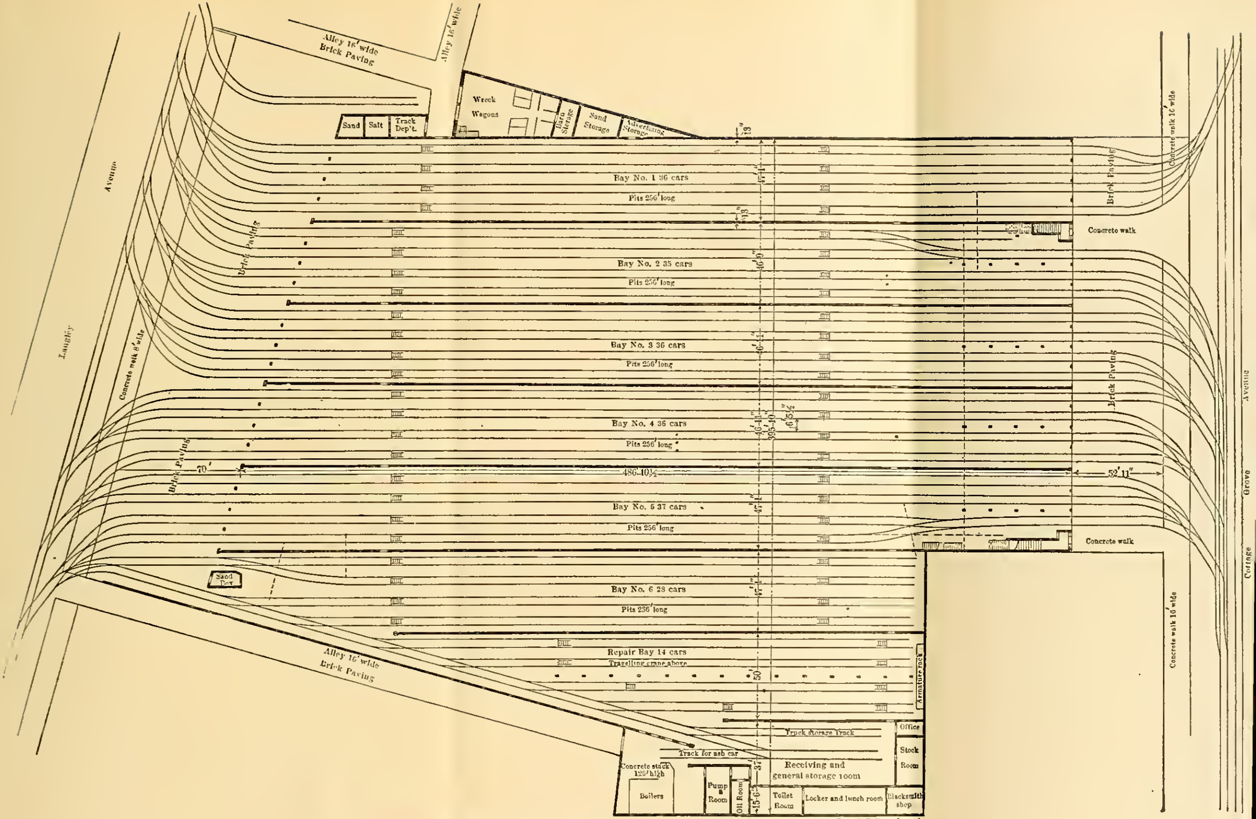
1 pipe-fitter's bench.

1 6-foot face plate, assortment of sledge-hammers and hand hammers, cutting chisels, drifts and jacks.

It should be understood, that only certain classes of work are handled in the carhouses. Whenever cars require general overhauling or repairing, they are sent to the main shops.

LIGHTING AND WIRING: All light and power wires are installed in conduits and according to the requirements of the National Board of Fire Underwriters. The general lighting is accomplished by means of arc lamps, five in series, on 500 volt circuit. The lights are staggered in various bays so as to provide general lighting between the rows of cars. Lighting in the pits is obtained by the use of incandescent lamps on 500 volt circuit, special arrangements having been made for pit lighting, in order to reduce the same to a minimum and yet provide the lights needed by the inspectors and repairmen.

The power supply for the building is controlled from what is known as the switch room. The power supply for each bay and the trolley wire leading from the same to the street is also controlled from this switch room, so that in case of fire in any one section, the power can be cut off from the same without interfering with the supply in the other sections, which would prevent the removal of cars from the danger zone.



Electric Railway Journal

Plan of Cottage Grove Avenue Car House—Chicago City Railway Company

This switch room has direct connection with the street, so that it would not be necessary for the operator to go through a burning section to pull the desired switch.

HEATING: The buildings are heated by direct radiation and in most of the buildings the vacuum system has been installed. In the original installation it was considered necessary to provide overhead coils in the vicinity of the sky lights, but experience has proven that the bays can be properly heated by locating the coils only in the pits and on the sidewalls in the immediate vicinity of the end doors.

The stacks in connection with the heating plants are of the reinforced concrete type.

UTILITY SECTIONS: Each division carhouse is provided with quarters for the following utilities:

1. Wreck and trouble wagons.
2. Track dept. section house and tool room.
3. Dry sand storage.
4. Salt storage.
5. Storage of summer and winter equipment, such as storm windows, screens, etc.
6. Stock room, containing material and supplies required for the carhouse maintenance work.
7. Advertising room.

INSURANCE: In the design briefly described above, special attention has been given to protection against loss by fire and the results obtained have been very satisfactory, as you will note from the following:

Comparison Statement—Fire Insurance.

Total Ins., 1906,	$6,441,869.00	Premium	$64,418.60	Rate	$1.00
Total Ins., 1906,	7,432,413.00	Premium	61,024.40	Rate	.82
Total Ins., 1907,	9,660,000.00	Premium	65,688.00	Rate	.68
Total Ins., 1908,	9,775,000.00	Premium	58,650.00	Rate	.60
Total Ins., 1909,	10,300,000.00	Premium	51,500.00	Rate	.50
Increased Ins., 1909,	$525,000.00	Decreased Premium	$7,150.00		

OPERATING METHODS: I have attached to this paper the principal blanks which are used in the carhouse repair and cleaning work, together with an outline describing the manner of using the same, which I will leave with the Secretary, so that any who so desire may have the privilege of examining the same. Briefly they consist of the following:

Motorman's Sign-In-Sheet, Exhibit "A."
Daily Record of Repairs, Exhibit "B."
Report of Cars Sent to Shop, Exhibit "C."
Report of Cars Returned to Service, Exhibit "D."
Repairman's Slip, Exhibit "E."
Car Placer's Record, Exhibit "F."
Daily Report of Carhouse Foreman, Exhibit "G."
Car Cleaner's Report, Exhibit "H."

CARHOUSE REPAIRS AND CLEANING.

Blanks and Forms as used on the Line of the Chicago City Railway Company.

Motorman's Sign-In-Sheet, Exhibit A.

Motormen are required to make a record of the condition of every car they operate. This applies equally to supply and work cars, as well as passenger cars.

Pads of these sheets are kept in trainmen's waiting room in a neat frame. Motormen state the time car is turned in, car number, condition of car, writes nature of defect, or O. K., and signs his full name.

After one of these sheets is filled out clerk to carhouse foreman takes it and enters on Exhibit "B," explained next; the report is then filled in by carhouse foreman in column showing "Action Taken." He here states "Repaired," "Held In," or "Sent to Shops."

After foreman finishes with sheet, showing action taken on every car reported, it is turned into office of Assistant Master Mechanic, who certifies to the correctness of the record.

At the end of each month the records from each carhouse are sent to the Claims Department for permanent file.

Daily Record of Repairs, Exhibit B.

This record is kept in carhouse, easily accessible to repairmen. Cars reported defective on Sign-In-Sheet are listed on this record. Down the left hand side are listed in alphabetical order, the parts of a car most frequently requiring attention. Car number is placed in proper column, and next to this column is a space in which the repairman places his pay roll number, after he had made the necessary repairs. This gives a record that the defects reported by trainmen have been repaired. Carhouse foremen can tell at a glance who the individual was that made the repairs.

The repair work is automatically distributed to the repairmen and a complete record of each day's repair work is kept on file in carhouse foreman's office.

Report of Cars Sent to Shop, Exhibit C.

Whenever necessary to send a car to the shops, one of these forms is filled out by carhouse foreman and accompanies the car to the shops. After repairs are made, shop inspector certifies on back of this record that he has inspected the car and same is in good condition, before it is sent back to carhouse.

In case of repairs caused by accidents in service, the expense of repairs is entered on back of slip.

Report of Cars Returned to Service, Exhibit D.

In case repairs could not be made on the same date as reported and it becomes necessary to hold the car in for one or more days, the carhouse foreman fills out one of these blanks for each car reported on Sign-In-Sheet as "Held In"; when he returns car to service he certifies to repairs having been made and this is sent with the Sign-In-Sheets to the Claims Department for permanent file.

Repairman's Slip, Exhibit E.

In order to further check the individual work of each repairman, he is furnished with these blanks, and his work, as taken from the larger record sheet, is entered on blank which shows the complete record of each man's work per day. This not only assists in Claims work in showing that car was repaired, but gives the foreman opportunity to trace back poor work to the individual.

Car Placer's Record, Exhibit F.

As cars are turned in by trainmen they are met by car placers who line up the cars in their respective bays (certain cars always being kept in a given bay).

Car placer enters on these sheets car numbers in the order that they are turned in. This gives permanent record of location of each car in the carhouse. On back of these reports car placer notes defects reported verbally by motorman when he turns car in. With this verbal report, the Sign-In-Sheets, and daily inspection made regardless of any reported trouble, it is seldom that a car is put into service in any way defective.

Daily Report of Carhouse Foreman, Exhibit G.

A daily report is made by each carhouse foreman to the Assistant Master Mechanic, showing statement of cars charged to that division, defective cars "Pulled In" and cars "Held In" for repairs.

The per cent of the "Pulled in" cars to cars operated is figured and noted on each day's report. These per cents are plotted on cross section paper Exhibit "H." Lines showing daily records of each car house are carried across the chart in color, each division having its indicating color.

These charts are drawn up to show two months' continuous operation. The weather condition is noted on the chart each day. This affords the individual responsible for the maintenance work a comparison of the character of the work at each division and by analyzing a peak on the chart by means of daily report showing what is causing the "pulls in" he can quickly tell what is causing the trouble on each division.

Car Cleaning.

Car cleaning, inspection, and repairing are arranged to be carried on progressively as the car is moved up from rear of carhouse, over inspection pits to storage tracks in front; cars are first met by cleaners who sweep floors and platforms.

All cars are swept each time they are turned in from service, but body cleaning (with exception of emulsion cleaning) is done when car is finally turned in at night.

Car Cleaner's Report, Exhibit H.

Each cleaner is required to fill out this blank showing total number of cars worked on and the class of cleaning he is required to do; from these individual slips a permanent record is maintained in a car cleaning book which shows the class and amount of cleaning work done on a car each month. This record is kept by the use of a set of symbols (see Exhibit "I") certain marks indicating a class of cleaning or inspection, or disinfecting.

Cars are cleaned with emulsion cleaner at intervals of about forty days and this cleaning is entered in record book in red pencil. By this means it is easy to tell which car is next in order for thorough cleaning with the emulsion process.

Terminal Cleaning and Repairs.

At the terminus of each line are men known as "Terminal Cleaners." These men are furnished with full supply of small repair parts, and are expected to make minor repairs, thus keeping in service many cars which otherwise would have been "pulled in." Also, each car is swept at the end of each round trip, thus keeping the floors and platforms always in a clean condition.

Chairman Abbott: I had hoped at this point in the program to have the pleasure of introducing to you Mr. John Z. Murphy, Chief Engineer of the Chicago Railways Company, but he is not able to be with us this evening. I can not, however, forego the opportunity to pay a tribute to the rare accomplishment of this engineer. Mr. Murphy's early experience and training as a marine engineer and as a sailing master taught him the useful lesson that, regardless of what sort of a craft he found himself afloat in, it was expedient to keep the craft afloat and bring it into port again. The necessities which his later position put upon him showed the value of his early training. Placed in charge of a traction system which was composed of overlapping and underlying systems of various sorts, and which was skillfully bound hand and foot by one of the ablest "financiers" of the country, Mr. Murphy with scarcely any visible means of support, I was going to say, to carry on his department, rebuilt his engines, rewound his generators, reconstructed his lines, rebuilt his motors, and kept going in fairly good, serviceable condition, a system which many would have been disposed to have shut down and called for a receiver to sell out. But Mr. Murphy, with his persistence, with his ingenuity, and his great energy, was able to keep the North and West Side systems going in a condition which furnished fairly good service to those two sections. We very much regret Mr. Murphy's inability to be here this evening.

Some twenty years ago it was my pleasure to have the next speaker of the evening check up my work and allow the estimates on it. I have been grateful to him ever since, for passing almost everything I turned in. Mr. Weston has grown up with the traction system of the city. He built the cable systems of the North and West Sides, and later on it was his privilege to see the mistakes of his earlier work and rip it out, and install electric systems instead.

It is my pleasure to introduce Mr. George Weston, Assistant Chief Engineer and representative of the City of Chicago on the Board of Supervising Engineers.

Mr. George Weston, M.W.S.E.: In response to your Chairman's request to address you this evening on matters pertaining to the workings of the Board of Supervising Engineers, I have prepared brief outlines of the ordinance requirements for rehabilitation of the properties and of the organization of the work, under the Chief Engineer, of supervising and inspecting this work. This is such a large field that it is impossible to cover each division in very much detail.

The Traction Ordinances of February 11th, 1907, authorized respectively the Chicago City Railway Company and the Chicago Railways Company to construct, maintain and operate, systems of street railways in the streets and public ways of the City of Chicago, and these Ordinances also created the Board of Supervising Engineers for the purpose of administering the said Ordinances.

The Companies agreed to proceed at once to rehabilitate and reequip their entire street railway systems and put them in first class condition as outlined in Exhibits B of the Ordinances, and in accordance with specifications prepared by the Chief Engineer of the work and approved by the Board of Supervising Engineers, and to conduct the work under the supervision of the Board.

The Ordinances provide that, if so requested by the City Council, the Companies will construct and equip extensions, not to exceed six miles of double track or twelve miles of single track for the Chicago Railway Company, and four miles of double track or eight miles of single track for the Chicago City Railway Company in each year after the three year rehabilitation period.

The Ordinances provide that, under certain conditions, the Companies are obliged to contribute an amount not exceeding $5,000,000 to the cost of construction of a downtown subway.

The Chicago Railways Company agreed to lower and reconstruct the tunnels under the Chicago River at Washington Street, and La Salle Street.

Certain specific service regulations are set forth in the Ordinances and the right is reserved to the City to secure adequate and sufficient transportation accommodations for the people, subject to the Board of Supervising Engineers as to the reasonableness thereof.

The Ordinances also provide for a modern type of double track passenger cars to be purchased by the Companies in the future, and stipulates that within three years from the respective acceptances of the Ordinances the Chicago City Railway Company must have in operation on its lines at least eight hundred cars of this modern type to be approved by the Board of Supervising Engineers; and the Chicago Railways Company must have in operation on its lines at least twelve hundred such cars.

Provisions are made for the use of a modern type of track rail with a thorough bonding of the rails at the joints.

The Ordinances further provide that all feeder and transmission wires shall be laid underground within that portion of the City bounded as follows:

> "Beginning at Lawrence Avenue and Lake Michigan, west "on the North side of Lawrence Avenue to Clark Street.
>
> "Southwest on the West side of Clark Street to Southport "Avenue.
>
> "South on the West side of Southport Avenue to Belmont "Avenue.
>
> "West on the North side of Belmont Avenue to Western Ave- "nue.
>
> "South on the West side of Western Avenue to 22nd Street.
>
> "East on the South side of 22nd Street to Halsted Street.
>
> "South on the West side of Halsted Street to 39th Street.
>
> "East on the South side of 39th Street to the East side of the "right-of-way of the Lake Shore & Michigan Southern Rail- "road.
>
> "And South and East along the right-of-way of the Lake "Shore and Michigan Southern Railroad to the southern most "point of the tracks of the Chicago City Railway Company.
>
> "Thence to Lake Michigan.
>
> "And along the shore of Lake Michigan to the place of be- "ginning at Lawrence Avenue."

This comprises an area of about forty square miles, requiring an installation of approximately six and one-half million duct feet of underground conduit.

The Ordinances also provide that the Companies shall build such power-houses, sub-stations, and other buildings, together with the necessary machinery and appurtenances as may be determined upon by the said Companies with the approval of the Board of Supervising Engineers to supply whatever electric power may be required.

The Ordinances also provide for the operation of twenty-one "Through Routes," designating the beginning and ending of the routes and the streets over which they shall be operated.

The books and accounts of the Companies are provided by the Ordinances, to be kept in such form as may be prescribed by the Board of Supervising Engineers, subject to the approval of the City Comptroller.

It will be seen by the above brief outline of the Ordinances that the Board of Supervising Engineers have been charged with a grave responsibility, and the Chief Engineer of the work with a task of most stupendous proportions in organizing the working force, directing the work of preparing plans and specifications, inspection of the work in the field, checking the accounts of the Companies, etc.

Owing to the magnitude of the work to be undertaken, the working force was organized into Divisions, and each Division placed in charge of a Division Engineer, who had specialized in the particular work included in his division.

The Divisions so determined are as follows:

Division D. Track and Roadway.
Division E. Electric Power Distribution.
Division G. Building and Fixtures.
Division I. Power Plant Equipment.
Division K. Cars and Car Routing.
Division P. Tunnels and Subways.
Division of Drafting—in charge of a Chief Draftsman.
Division of Accounts—in charge of a Certified Public Accountant.

The working force of the Chief Engineer's organization comprises one hundred and thirty-seven persons, consisting of Engineers, Accountants, and general office employees.

On March 30th, 1908, the City Council of the City of Chicago passed an Ordinance authorizing the Calumet & South Chicago Railway Company to construct, maintain and operate, a system of street railways in the streets and public ways of the City of Chicago.

This Ordinance was drawn upon lines similar to the Ordinances of February 11th, 1907, providing for a Board of Supervising Engineers, etc., and providing for the rehabilitation of the property, including forty miles of single track.

This company consolidated the Calumet Electric Street Railway Company and the South Chicago City Railway Company, and the respective properties of the Companies into one Company, with a total mileage of 98.44 miles of single track.

The City Council of the City of Chicago passed an Ordinance March 15th, 1909, to the Southern Street Railway Company (formerly the Chicago General Street Railway Company) drawn upon lines similar to the Ordinances of February 11th, 1907, providing among other things, supervision by the Board of Supervising Engineers, and the rebuilding of its property, including about seven miles of single track.

The Ordinances also made provisions for an Operating Agreement between the Southern Street Railway Company and the Chicago City Railway Company, whereby the Chicago City Railway Company was to conduct the work of rehabilitation, and to operate the road as a part of its own system. The Southern Street Railway Company own about 18 miles of single track.

In addition to supervising the rehabilitation and checking the accounts of the Chicago City Railway Company and the Chicago Railways Company, the above organization is looking after the work of the Calumet & South Chicago Railway Company, and the Southern Street Railway Company, the joint Companies comprising a total of 651 miles of single track, and the immediate rehabilitation of 280 miles of single track.

October, 1909

The Division of Track & Roadway was organized in May, 1907, and track construction work was commenced June 17th, 1907, on Root street between Wallace and State streets, by the Chicago City Railway Company. Three types of track have been designed and approved by the Board of Supervising Engineers, differing principally in respect to the foundation.

Type No. 1. Consisting of steel ties in concrete.
Type No. 2. Consisting of wooden ties in concrete.
Type No. 3. Consisting of wooden ties on a rolled stone foundation, with concrete between and on top of the ties, to provide a foundation for paving.

The rails, tie fastenings, paving, etc., of these different types are practically the same excepting that screw spikes are used with wooden ties, and with steel ties, a special clip to fasten the rail to the tie. One of the features of the track construction is that by the use of screw spikes on wooden ties or a removable clip on steel ties, the rails can be removed and replaced without disturbing the track foundation and without damage to the ties.

Several miles of Type No. 1 track with steel ties have been built by the Chicago City Railway Company, but the Chicago Railways Company have not used this type of track.

The tracks built to date by both Companies consist principally of Types No. 2 or No. 3, and the greatest mileage has been constructed using Type No. 2 construction, or a modification of the original Type No. 2, styled Type No. 2-A, which differs from Type No. 2 only in respect to the spacing, center to center, of ties.

The Ordinances provide that during the three year rehabilitation period the Chicago City Railway Company shall rebuild all of its cable tracks, and sixty miles of electric track, a total for that Company of ninety-five miles of single track; and the Chicago Railways Company shall rebuild all of its cable track and ninety miles of its electric track, a total for that Company of one hundred and thirty-eight miles of single track; a grand total for both Companies of two hundred and thirteen miles of single track. In addition to the above rehabilitation work, the Ordinances provide for about 65 miles of single track extensions.

The Chicago City Railway Company has completed to date about 84.7 miles, or 90% of the ordinance requirements for track reconstruction; and the Chicago Railways Company about 93 miles, or 68%

The Chicago Railways Company had finished about 50% of their total rehabilitation and new extension requirements at the close of the year 1908, and have laid out a schedule for this year amounting to one hundred and twelve miles of single track, based upon a working schedule of thirty-six weeks; this equals an average of 3.11 miles of finished track per week. Up to this time the Company has practically averaged this schedule.

The Chicago City Railway Company have remaining but a few miles of rehabilitation track work to complete their Ordinance requirements and can easily finish during the present year.

The Calumet & South Chicago Railway Company have rebuilt but 2.5 miles to date of the 40 miles required by the Ordinance, but their schedule for the year of 1909 comprises twelve and one-half miles of single track rehabilitation work and about four miles of new extensions.

The seven miles of track rehabilitation for the Southern Street Railway Company is scheduled for building this year.

Track special work is a very important part of any street railway system, and this subject has been given careful study and consideration by Division D, the Engineers of the railway companies, and the Board of Supervising Engineers; and specifications covering the manufacture of special work have been prepared, under which all special work for the companies under the jurisdiction of the Board of Supervising Engineers is manufactured.

There has been placed to date during the rehabilitation period one hundred and thirty-two special work layouts and in addition seventy-nine crossovers by the Chicago City Railway Company and the Chicago Railways Company, a large percentage of which being our Type B construction, of which the curved frogs, crossings, switches and mates are solid manganese castings. All curves have been designed for safe operating clearances between cars of all types passing in any direction. During the past year specifications have been prepared covering the manufacture of open hearth steel rail, and all rails contracted for the current year will be manufactured under this specification.

The Division of Electric Power Distribution was organized during May and June, 1907, and the work of this division comprises the Electrical Transmission and Distribution Systems, consisting of underground conduit, underground and overhead feeders, underground and overhead transmission lines, trolley and its connections, bonds, auxiliary cables and telephone systems; and includes the testing of track joints for relative conductivity. Plans and specifications have been prepared by this division for typical underground conduit construction, which comprise three general types of construction:

Type A, square bore multiple duct.
Type B, round bore single duct installed in cable slot.
Type C, square bore single duct.

Typical construction for standard sizes of manholes have been designed, including concrete and brick construction. The manholes are principally being constructed of brick on account of this type of construction being more flexible than concrete construction, facilitating the working around other conduit lines, water pipes, gas pipes and other street obstructions. The larger number of manholes constructed are of the barrel shape, for the reason that this form of manhole reduces the cost to some extent and leaves a wall face, which is more satisfactory for the training of cables.

In the early part of the work some multiple duct conduit was constructed, but it was later decided to make the single duct square bore construction standard for all Power Distribution work.

Specifications have been prepared for,
Single conductor, rubber insulated, lead sheathed cables.
Three conductor, paper insulated, lead sheathed cables.
Installation of lead sheathed cables and underground conduit.
Steel armored, lead sheathed, cables for submarine construction.
Triple braided weatherproof copper cables.
Hard drawn copper wire.
Single conductor, paper insulated, lead sheathed, copper cables.
Single conductor, paper insulated, lead sheathed, aluminum cables.
Single conductor, rubber insulated, lead sheathed, aluminum cables.

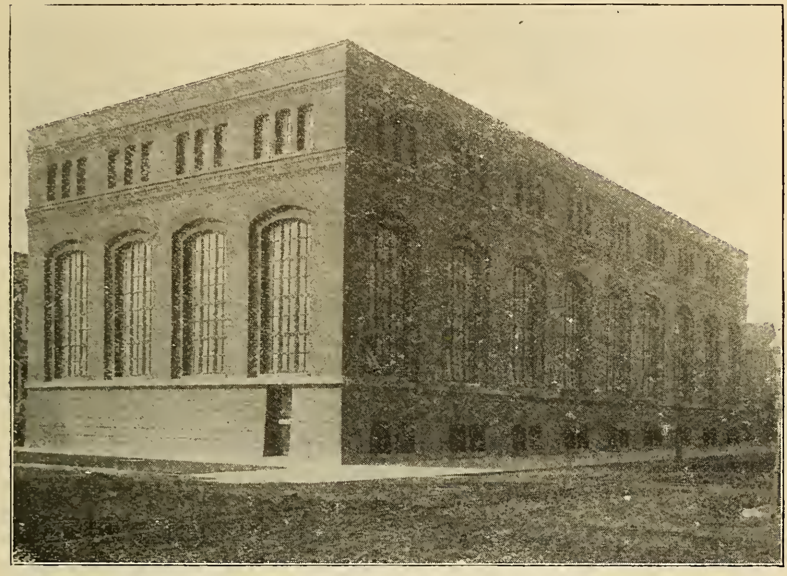
In calculating the feeders for the D. C. distribution system, the various lines of the Companies have been divided into trolley sections, and the maximum two hour schedule of cars upon each trolley section has been taken, and with this as a basis, and making a liberal allowance for average current consumption at the car (which I might say has been determined by actual observations and tests) the c.m. capacity of cable for each line has been determined, the maximum drop for heavy traffic sections being fifty volts, which has been increased somewhat on remote sections.

In figuring the negative return system, a drop of 25 volts at extreme points from the source of supply has been taken as a basis for figuring, and inasmuch as our Ordinances require that the conductivity of the rail at the joint shall be equal to the conductivity of the rail itself, and from the fact that this condition is obtained through the use of electric welded joints, full credit is given in these calculations for the carrying capacity of the track rails, and additional bare copper cable is added in order to keep the auxiliary return circuit in all locations within the specification requirement of 25 volts drop. In calculating the negative return, it is assumed that all current returns to the station from which it originates.

At all track special work layouts, each straight track rail is supplemented by a copper cable throughout the entire length of the special work, and the ends welded to the rails on each side of the special work layout.

Division G—Buildings and Fixtures—was organized in May, 1907, and took up the inspection of the construction and completion of sub-station buildings of the Chicago City Railway Company, located at 20th and Dearborn streets, 63rd street and Wentworth avenue, and 42nd and Wabash avenue, as well as two new fireproof carhouses for the Chicago City Railway Company, one located at 38th street and Cottage Grove avenue, and the other at 77th and Vincennes Road, plans for all of which buildings had been prepared by the Chicago City Railway Company and had been approved by the Chief Engineer of the Work.

In September, 1907, this division began to keep in touch with the building work of the Chicago Railways Company, and after the acceptance of its ordinance by the Chicago Railways Company,



Electrical Substation at 42nd St., and Wabash Ave.

Car barn at 69th St., and Ashland Ave.

January 28th, 1908, this division, in conjunction with the Engineers of the Chicago Railways Company, prepared plans and specifications for new fireproof carhouses of the double end type, and fireproof substation buildings.

Five new car houses are in course of construction by the Chicago Railways Company at this time; one located at Leavitt and Twenty-fifth streets; one at Sheffield and Wrightwood avenues; one at North Clark street and Dewey Court; one at Kedzie avenue and Van Buren street; and the fifth, at Ogden avenue and 22nd street, capable of housing 834 double truck cars; and designed as regards facilities for handling and cleaning the cars, fire protection, etc., on the general lines outlined by Mr. Fleming in his paper presentd here this evening. In addition to the new car houses of the Chicago City Railway Company previously referred to, located at 38th and Cottage Grove Avenue and 77th and Vincennes Road, two additional car houses have been completed and are in operation, one located at 38th street and Archer avenue, and the other at 69th and Ashland avenue, making a total of four large modern fireproof car houses for that Company, capable of housing 1,076 large double truck cars.

Division I—Power Plant Equipment.—Steps for organizing this division were taken in the month of May, 1907, and the initial work undertaken was to inventory and value the betterments to the Power Plants and Substations of the Chicago Railway Company since the date of the original valuation, June 30th, 1906. In July daily inspection of the work in progress at every substation was commenced and daily reports made of the labor and materials used.

At the time of the organization of the Board of Supervising Engineers, the Chicago City Railway Company had in operation three steam plants, (one of which was operated only during the winter months) for the generation of electricity for operating its lines. This Company also obtained a large amount of electrical energy from the Commonwealth Edison Company through their two rotary converter substations.

Since the organization of the Board, additional substations have been built and put in operation, and a contract entered into with the Commonwealth Edison Company whereby all of the current required for the operation of the railway is purchased, and the Company receives at its substations, 25 cycle—9,000 volts—3-phase current, generated at the Fisk Street Power Plant of the Commnwealth Edison Company and delivers 600 volts to the direct current feeder system of the Road.

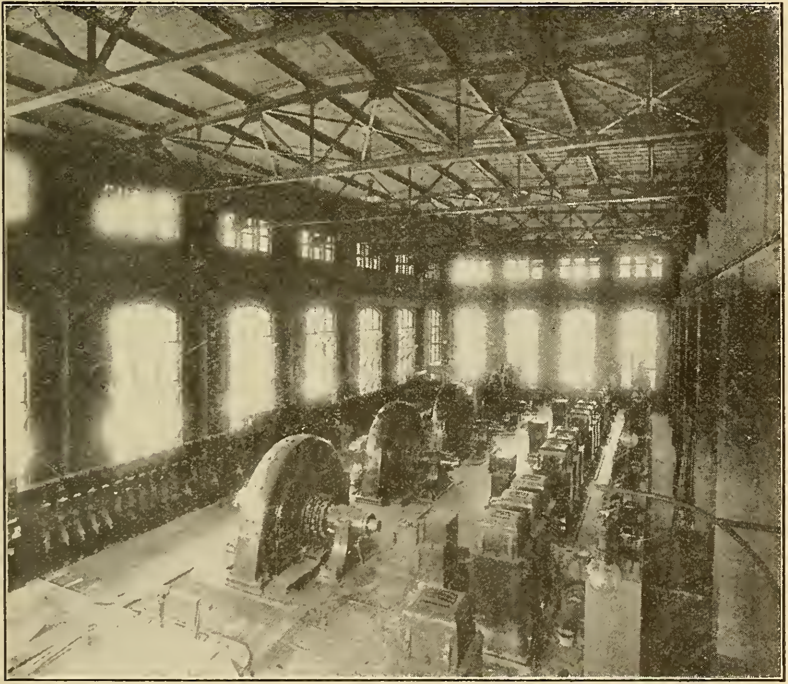
Five substations have been estimated as being required to supply the necessary electric current to the system of the Chicago City Railway Company when rehabilitated; a total ultimate capacity of 50,400 kw., exclusive of storage battery at Plymouth Court Substation.

Four substations were built prior to February 1st, 1908, and construction work on the fifth substation building has been commenced.

All substation buildings of this Company are designed of substantial fireproof construction, with pressed brick walls both inside and out; book tile roofs carried on structural steel trusses, of composition roof covering, concrete floors, with a red tile wearing surface, all thoroughly fireproof and architecturally first-class.

The capacities of these substations and their locations are as follows:

20th and Dearborn Streets substation: total capacity 12,000 kw. Present rotary converter equipment consists of four, 2,000 kw. units and three, 1,000 kw. units.



Interior view of Substation at 42nd St., and Wabash Ave.

63rd and Wentworth Avenue substation. When extended to its full capacity this station will accommodate 12,000 kw. There are at present three, 2,000 kw. and three, 1,000 kw. rotary converter units.

42nd and Wabash Avenue substation; total capacity of substation 14,000 kw. There are at present five, 2,000 kw. rotary converter units in this station.

48th and Honore Street substation. Total capacity of this substation 10,000 kw. There is being installed at present three, 2,000 kw. rotary converter units.

Plymouth Court Substation. This substation is one of the Commonwealth Edison Company's buildings in which the Chicago City Railway Company have been given space for the placing of two 1,200 kw. rotary converter equipments and one large storage battery. The storage battery has a rated capacity of 2,240 kw. for one hour. An exterior and interior view of the 42nd and Wabash avenue substation is shown. These views are typical of all the substations of the Chicago City Railway Company.

At the time of the organization of the Board, the Chicago Railways Company had two steam power plants in operation; one at Hobbie street on the North Side, and one at Western avenue and Washington street on the West Side, both of which stations generated direct current for the use of the railway. In addition to the current generated at these substations, some current was purchased from the Consolidated Traction Company, and the old Cable Plant at Van Buren street and Washington street was being converted into a substation, the Company obtaining 25 cycle—9,000 volts—3 phase current from the Commonwealth Edison Company's high tension lines, and delivering 600 volts direct current to the railway feeder system. Since the organization of the Board, this substation has been enlarged and three new substations are in the course of construction; one located at Sheffield and Lill avenues on the North Side; one at Leavitt street and Blue Island avenue on the Southwest side; and one at Grand avenue and Fortieth avenue on the Northwest side. The capacity of these substations is 6,000 kw. each; a total of 18,000 kw.

There is now being installed at the Sheffield avenue and Lill avenue station, and the Leavitt street and Blue Island avenue station, 4,000 kw. each, and the first installation at Grand avenue and Fortieth avenue will be 4,000 kw., leaving a reserve for these three stations of 6,000 kw.

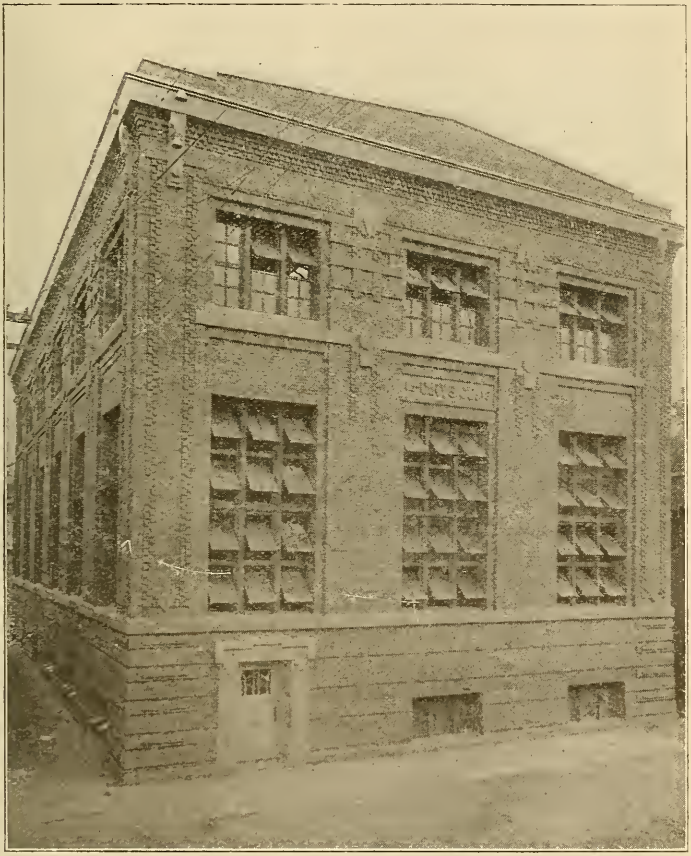
There is installed and in operation at the Van Buren street substation 10,000 kw., and an additional unit of 2,000 kw. being installed, which will make the installation up to date for that station 12,000 kw.

The old cable plant at Milwaukee avenue and Cleaver street has been rebuilt, and the boiler room section of the station converted into a substation. Total ultimate capacity 8,000 kw. Present installation, 4,000 kw., and an additional 2,000 kw. unit is being installed.

There is also under consideration the location of a substation on the North Side, somewhere in the vicinity of Devon avenue, of 6,000 kw. capacity, making a total substation capacity when completed of 44,000 kw. for the Chicago Railways Company.

The new substations that are being constructed by the Chicago Railways Company are designed of fireproof construction, with pressed brick walls, both inside and out, book tile roofs, carried on structural steel trusses, and composition roof covering, concrete floors with composition wearing surface.

If time permitted, it would be interesting to describe in detail these substations, the design and equipment of which, as well as the quality of material and workmanship which is used throughout their construction, is believed to approach the highest standard of engineering practice.



Electric Substation, Lill Ave., near Sheffield Ave.

Division K—Cars and Car Operation—was organized in July, 1907, and its work consists chiefly of the working out of dimensions, weight, lighting, braking, ventilation, and other features that enter into the construction of typical modern double truck cars for street railway service, as are outlined in and contemplated by the Traction Ordinances.

The car that has been adopted as standard up to the present time is what is known as the Pay-As-You-Enter car, seating 40 passengers.

The standard car of the Chicago City Railway Company is 48 ft., 3 in. in length and 9 ft. wide, over all. The platforms are 7 ft., 11 in. long over all, and 6 ft., 11 in. long inside, affording large, and commodious loading floor space.

The Chicago Railways Company are now building 650 cars of the Pay-As-You-Enter type 49 ft., 2 in. in length and 8 ft., 9 in. wide over all. Length of vestibules 8 ft., 4½ in. over all.

Special attention has been given to lighting and heating. The lamps for interior illumination are placed one over each seat, and are frosted globes, doing away with the glare of the ordinary incandescent bulb, and providing a soft and pleasant light. The heaters are electric and possess the advantage of compactness, light weight, cleanliness, flexibility of regulation, etc. Special heaters are provided on the platform for the comfort of the motorman and conductor.

The cars are equipped with sliding disappearing or folding steps, thereby making it possible to have the side of the car in the center between tracks or the non-loading side of the car closed, and no protruding steps or other parts permitting hitching on or standing on the outside, thus eliminating the possibility of accident from that source.

Cars are equipped with both air and hand brakes. The motor equipment consists of 4—40 H.P. motors per car.

Of the 650 cars under construction by the Chicago Railways Company, 600 are composite construction with steel underframes, and wooden body, and are being built by the Pullman Company. The remaining 50 are all steel cars, being built by the Pressed Steel Car Company at McKees Rock, Pennsylvania.

To our Chairman, Mr. Bion J. Arnold, is due the credit for the purchase of these steel cars, as he, in connection with his work on the New York subway problem, recognized the advantage to be gained by the operation of steel cars in subways rather than wooden cars. Inasmuch as we hope to have a subway in Chicago some time in the future it was concluded wise to begin the study of the construction of steel cars and their maintenance, cost, comparative life, etc., hence the 50 cars now in course of construction. The design of these cars, as far as dimensions over all, general interior arrangement and general appearance, are identical with the wooden cars being manufactured by the Pullman Company, but with the exception of the doors, car steps, trolley board, and maple floor strips, the cars are steel construction and practically fireproof throughout.

Division P—Tunnels and Subways—was organized in February, 1908, after the acceptance of its ordinance by the Chicago Railways Company. The Ordinances to that Company provide that it shall rebuild the tunnels under the Chicago River at La Salle street, and

Washington street; and plans and specifications have been prepared for a double bore reinforced concrete tunnel at La Salle street, so designed that it can be connected with and become part of any subway system that may be designed in the future, and provisions for temporary approaches from the surface so that the surface cars operating between the North and South Divisions of the city can have the benefit of this tunnel in the operation of cars to relieve the present congestion on the bridges. It is expected that contracts will be let covering the construction of this tunnel in the near future.

Plans and specifications are also under way for the complete reconstruction of the Washington Street Tunnel, which will be designed for connection to any system of subways that may be built in the future, and also with temporary approaches to the surface. Plans have been completed for a section of this tunnel on the west side of the river between Clinton and Canal streets, and a contract has been awarded for this part of the work to be carried on in conjunction with the construction of the terminal station of the Chicago & Northwestern Railroad, which crosses Washington boulevard at that point.

The Drafting Department—was organized under a Chief Draftsman who has general supervision of the work performed in the department and of the various systems and records required. Reporting directly to the Chief Draftsman are a clerk and four squad foremen; each of these is held directly responsible to him for the correct and proper execution of the work performed under his supervision. Each squad foreman is assigned to a special class of work and as the needs or demands of that particular work require draftsman or tracers they are accordingly detailed in order to secure the best and most desirable results. The Chief Draftsman receives instructions from the Division Engineers respecting the engineering details and design of the drawings made for their respective divisions, all of which work is under the immediate direction of the Assistant Chief Engineer. The drafting department is also called upon to supply all sketches and drawings required by the different divisions and also to meet the demands for minor jobs consisting of printing, binding, pasting, mounting, labeling, rolling, folding, indexing, etc.

All drawings are on standard size sheets, which sizes are multiples of the regular letter size sheet—8½ in. by 11 in., and the other sizes can be folded down to 8½ by 11 in. for filing purposes.

No. 1. 8½ by 11 in.
No. 2. 34 by 22 in.
No. 3. 34 by 44 in.

and in addition drawings that are larger than size No. 3 are called "Rolls" and are designated in size as "R" drawings.

For convenience each division has a classification letter which corresponds with the letter used in the classification of accounts by the American Street Railway Accountants Association.

Track and Roadway—Division D.

Electrical Transmission—Division E, etc., and drawings are indexed to denote the size of sheet and division as follows:

Track and Roadway—Division D drawings.
No. 1—D.
No. 2—D.
No. 3—D.
R—D.

Electrical Transmission—Division E drawings.
No. 1—E.
No. 2—E.
No. 3—E.
R—E.

and the drawing number for each drawing follows. The filing system consists of six groups or divisions:

Domestic Tracings.
Domestic Blueprints.
Folios.
Foreign Prints.
Catalogues.
Miscellaneous.

The Division of Accounts—was organized in May, 1907, and has charge of checking all expenditures that relate to the cost of rehabilitation, and to ascertain with the assistance of reports from the Engineering Divisions whether or not such expenditures are reasonable and to determine whether such expenditures are proper charges to Capital Account, in accordance with the rulings of the Board; and to determine whether proper reserves have been created and are maintained by the Companies as set forth in the Ordinances. Also to keep account of all expenditures made by the Board in the carrying out of its duties, which expenditures, in accordance with the terms of the Ordinances, are to be added to Capital Accounts of the railway companies during the period of rehabilitation, and after that period are to be charged to operating expenses.

Capital Account money is new and additional money put into the property to improve and extend it, and is obtained from other sources than the cash receipts of the Company.

The Ordinances provide that out of the gross receipts of the Company shall be paid—

1st. The operating expenses, including taxes.

2nd. The ordinary repairs to the physical property for which a sinking fund is provided, the minimum amount of which shall be 6% of the gross receipts per annum.

3rd. The renewals or depreciation of the physical property for which a sinking fund is provided, the minimum of which shall be not less than 8% of the gross receipts per annum.

4th. Out of the gross net earnings remaining after deducting the above charges, the Company may retain 5% upon the capital account as approved by the Board of Supervising Engineers.

5th. The remaining net earnings are divided 55% to the City and 45% to the respective Company.

During the rehabilitation period of three years from the date of the acceptance of this Ordinance, a special manner of accounting is provided, covered by the following quotation from the Ordinances:

"The said Board of Supervising Engineers shall have power "to determine what work shall be treated as construction, re-"construction, equipment, re-equipment, extensions, new lines, "underground trolleys or additions to plant or property to be "paid for by the Company out of the capital funds to be "provided by it for that purpose, and what shall be treated as "maintenance, repairs and renewals, to be paid for out of the "gross receipts of the Company from the operation of the street "railway system hereby authorized. But any such determin-"ation of said Board shall be governed by the following pro-"visions:

"During the three (3) year period of "Immediate Rehabili-"tation" seventy (70) per cent of the gross receipts shall be "set apart and shall be used so far as required in defraying "the operating expenses, including maintenance and repairs, "and the residue of said seventy (70) per cent. shall be ap-"plied to the cost of renewals and no part of the cost of any "renewal paid for out of such seventy (70) per cent. shall be "charged to additional capital, and all expenditures for re-"newals during said three (3) years in excess of such residue "of said seventy (70) per cent. shall be charged to capital ac-"count.

"After such three (3) year period of 'Immediate Rehabil-"itation,' the cost of renewals shall be paid as provided in "Section 16 hereof, but such expenditures (and only such ex-"penditures) as are made for the purpose of extensions of or "additions to property shall be thereafter considered as addi-"tions to capital, provided, however, that in the replacement of "any principal part of the property, either existing or hereafter "acquired, there shall be charged to capital the excess amount "that the new property cost over the original cost of the prop-'erty displaced, excepting that the value of property contained "in the appraisal inventory of the property of the Company, "referred to in Paragraph 1 of Section 20 hereof, shall be used "instead of first cost for all property listed in such appraisal "inventory."

Each Division Engineer has, as a part of his organization, Inspectors, who, in addition to their other duties, render to him on forms daily, semi-monthly and monthly reports of the quantities and amounts of material used and hours of labor expended on each piece of work in progress. These reports are used by the division engineer as a basis for the monthly estimates and also as a check upon the expenditures made by the railway companies and reported by them to the Division of Accounts. Thus, a counter check from two entirely independent sources are secured; from reports of the railway companies checked and summarized by the Division of Accounts and from the field reports of the Division Engineers. If time would permit, a much more detailed account of the workings of the division of accounts, and the methods of checking the amounts expended on the rehabilitation work by the different engineering divisions would probably be of interest.

Mr. William B. Jackson, M.W.S.E.: I regret that Chairman Abbott had to leave for a train, so that we cannot have the pleasure of hearing further from him tonight. I wish to express, for both Societies, our great appreciation of the talks that we have had this evening.

In connection with some of the matters that were brought out by Mr. Fleming and Mr. Weston regarding the question of blanks that are in use by the traction companies, and the matter of typical designs for substations, car barns, etc., the Societies will certainly appreciate any designs that may accompany the papers for use in the proceedings, so that, although it was not possible to explain in detail many of these designs, we shall have the opportunity of studying them in the JOURNAL of the Society.

We have with us tonight one of the men who has been much interested in all traction problems of Chicago and who has been in this work for a long time, and I take pleasure in calling upon Mr. B. I. Budd, General Manager of the Metropolitan West Side Elevated Railway Co.

Mr. B. I. Budd: I have listened with much interest to the outline of the great work being carried on by Mr. Arnold and the Board of Engineers. There is one question I would like to ask in regard to the work of rehabilitation. The congestion, delays, and consequent loss of time in getting cars through the heart of the city at the present time would indicate that, even with the present amount of new equipment operated, the tracks have nearly reached the limit of their capacity, and I would like to hear from one of the Board of Engineers what their plans are to relieve this congestion.

Mr. Arnold: Of course we cannot make any more streets in the city than we now have. If we could we would, for we need them. But it is expected when we get these tracks all reconstructed, in accordance with the terms of the ordinances, that the cars will be so re-routed by means of the through routes that the congestion now existing will be relieved; in other words, many of the cars which now come into the down town district, around the loop, and return, will then run through, thus relieving the congestion.

Chairman Jackson: We are all looking forward to this through routing. I remember how I was looking forward to it when I was living on the North Side near the lake last year. I was thinking about how pleasant it would be to go right to my office on the North State Street cars. Then about the time we had that through route, I moved further out and missed the opportunity to use it, but my experience gave me a lively appreciation of the need and advantages of the through routing.

Mr. Arnold: Just a word further; we are now substituting single cars for trains, thus putting one car on the street in place of two; in many instances this will tend to relieve the congestion that Mr. Budd speaks of, also, the additional power on the cars being larger motors, gives a more rapid acceleration and enables us to increase the speed of those cars about 11%, which also tends to help relieve congestion. I might also state that we hope in the course of time to have subways, for which we all ought to work. As a general proposition, we need all the space on the surface of the present streets, we need all the space under the streets, and we may need all the space above the streets, to take care of the traffic of this city in the years to come.

Chairman Jackson: We have heard much of great interest regarding the mechanical features of the street railway construction and regarding the franchises, etc. Every foot of this system uses electric power in its operation, and aggregates in length of single track a distance equal to that from New York to Boston. I believe there are some 75,000 to 80,000 kw. of rotaries, operated from the great central power plants of the city, which supply electric energy to the system, and I will ask Mr. Junkersfeld, who is the Electrical Engineer of the Commonwealth Edison Company, to tell us something about the electrical distribution required for the system.

Mr. P. Junkersfeld, M.W.S.E.: I have been very much interested and very much instructed by what we have heard here this evening. One of the underlying theories of the ordinances, as I understand it, in addition to what has already been said, was to give the best possible service for the present rates of fare, and that takes into account, of course, everything, including the power. The Commonwealth Edison Company, as has been said, furnishes at the present time motive power for the City Railway and quite a large amount for the Chicago Railways. At this time such power is all generated in two power houses, one at Fisk street, which is known as the Fisk Street Power Station, and the other one, which is across the river therefrom, known as the Quarry Street Station. Those two power houses are sufficiently familiar to most of you to require no further description, except perhaps the general statement that the Commonwealth Edison Company in supplying this power, has likewise kept in mind that the best possible service that can be rendered is the only one that is acceptable and the one which is in line with this great development going on in the traction situation. We have spared no expense, and the best and most modern equipment that can be secured has been installed and is used to furnish this power. In the transmission system as well, every precaution known to the best modern practice is used and taken to guard against accident or interruption.

Mr. D. W. Roper, M.W.S.E.: In his remarks about the division of the receipts, Mr. Arnold told us how certain parts were paid for operating expense and certain other parts for depreciation of parts and to add interest on the investment, and 55% of the remainder or net receipts went to the city as its compensation. I would like to inquire what percentage of the gross receipts the city's compensation approximates.

Mr. Arnold: I have not the figures exactly, but I will say during the two years that we have been in operation we have put into the city treasury very close to $3,000,000. If you will figure that up I think you will find it is approximately 8% of the gross receipts for the two years.

Now, let me make that point clear. When these traction ordinances were under consideration, that question, you remember, was made a feature of the campaign prior to the adoption of the ordinances by the city. Certain people having the interests of the city at heart requested that the ordinance be so modified as to stipulate that this 55% of the net receipts should never be less than a certain per cent. of the gross receipts, they contending for 10%, I believe, of the gross receipts. That question was put right up to myself, who was the engineer representing the city at that time, and Mr. Weston, my assistant at that time, and we spent many nights working out the probable results for the period of twenty years covered by these ordinances. We found that we could not recommend that the railway companies guarantee the city 10% of the gross receipts and at the same time require them to build the kind of a railroad that we, as engineers, said the city ought to have; consequently we told the gentlemen who were interested in it—a very important body of men in the city, all having the interests of the city at heart—that it could not be done; that if they wanted a railroad such as we thought they ought to have, they had better waive the 10% of the gross receipts feature and take 55% of the net receipts; if they demanded 10% of the gross receipts, the investment would have to be so low that we would not get a good railroad. The result was, it was decided not to change the ordinances. Those advocating the ordinances stood upon the ordinances as they read, namely, 55% of the net receipts, and this was ratified by the people, as you know, by 35,000 majority. There may be times when it will be 10% of the gross, but the average for the period according to our estimates, was approximately 8% of the gross receipts.

Chairman Jackson: Are there any further remarks or questions? If not, I will ask Mr. Arnold to speak in closure for the Board of Supervising Engineers.

I would like to ask how the value of real estate was determined, and whether the railroads were given the benefit of the advance in the value of the real estate up to the time of the appraisal? Also what was done in the matter of such costs as legal expenses, cost of marketing and securities, incidental expenses, etc.

Mr. Arnold: The question of real estate, I will answer first. We took an appraised valuation of the real estate at the time the valuation was made, June 30, 1906. That valuation was determined by real estate experts whom we employed, familiar with property values in the city; they went out and examined the properties. The railroad company sent one expert and the city sent one expert. They submitted their figures to us independently, and when the differences were too great we asked them to go back and look at the properties again. The result was that they finally came to conclusions on every piece of real estate and those are the values we accepted. Those values recognize whatever increase had been made in the properties from the time they were purchased by the companies to the time of the valuation. Consequently we took the actual valuation of the properties. The companies contended for certain expenditures which they had made in the way of bridges and other city improvements, concessions to the city for the right to lay tracks in the streets, which of course had cost the companies money. Certain facts were more or less recognized in fixing the compensation. When we thought an article should be allowed we allowed it; but we did not allow anything for construction of bridges, reconstruction of bridges or things of that character, because we thought that they had had the use of the bridges long enough under the ordinance to compensate them for any expense of that kind.

In general, I may state that this whole question is a vital one at the present time. As some of you know, I am appraising all the street railway properties in New York, in Brooklyn, and in Detroit, and this question Mr. Jackson has raised comes up at every place and is a very serious one. I do not know that I have clearly settled in my own mind what we will do, but in general such expenses are always impediments in the way of getting properties together. For instance, when you consolidate properties you generally have to have a capitalization of more than they originally cost, because somebody makes a profit, and such promotion expenses, legal expenses, and other expenses of that character, which go into the creation of a property, should probably be put into a fund to be charged off gradually over a period of years, so that finally the property will not have to carry the burden of them, in its capitalization; and that is about the position I am getting to, although I have not absolutely taken that stand yet.

Chairman Jackson: In other words, you aim to protect the stockholder and at the same time protect the people?

Mr. Arnold: Yes, and protect the man who builds the railroad in the first place. He can not create the railroad without incurring those charges, because they must be incurred, and in order that he may finally get his money out of them, the theory is that he should have a certain number of years during which a percentage of these charges should be charged off each year, so that finally the capitalization is reduced by that amount. Then the innocent purchaser in future only pays upon the real value of the property, promotion charges having been wiped out. The English have some such plan as that, and it seems to be a pretty good one.

I don't know that I can add much further information to either of the questions we have just been discussing. We can talk about them all night, because there are so many elements that enter into them. What are promotion charges? What are proper charges to capitalization? How long a period of time should we charge it off in? What kind of a fund should we create? What would we do with that fund while creating it? Those are things that are vital and have got to be settled in the near future in this country. It is a live question in every city that has a traction question.

I wish to express my appreciation, on behalf of the Board of Engineers, for the opportunity which you have given us to appear before you to-night and talk about our own affairs, and I hope that we have been able to give you some information that may be of possible value to you.

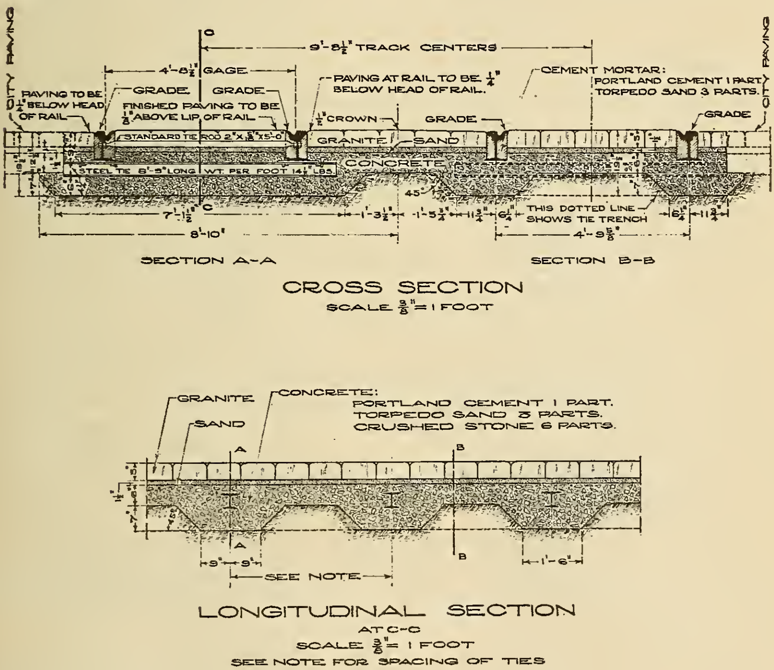
RECONSTRUCTION OF STREET CAR TRACKS IN CHICAGO

George Weston, M.W.S.E.

Presented June 16, 1909.

In presenting this paper it is not claimed that anything specially new in Track and Roadway Engineering has been developed in the plans and methods that have been adopted for the reconstruction of the street railway tracks of Chicago; however, the use of screw spikes and treated ties may be new in their application to street

TYPE #1.


CITY PAVING
CITY PAVING
9'-8½" TRACK CENTERS
4'-8½" GAGE
PAVING TO BE 1¼" BELOW HEAD OF RAIL
GRADE
GRADE
FINISHED PAVING TO BE ⅛" ABOVE LIP OF RAIL
PAVING AT RAIL TO BE ¼" BELOW HEAD OF RAIL.
½" CROWN
GRADE
CEMENT MORTAR: PORTLAND CEMENT 1 PART. TORPEDO SAND 3 PARTS.
GRADE
STANDARD TIE ROD 2"X⅝"X5'-0"
GRANITE
SAND
CONCRETE
STEEL TIE 8'-9" LONG WT. PER FOOT 14½" LBS.
45°
C
7'-1½"
1'-3½"
1'-5¾"
11¾"
6¼"
THIS DOTTED LINE SHOWS TIE TRENCH
6¼"
11¾"
8'-10"
4'-9⅝"
SECTION A-A
SECTION B-B
CROSS SECTION
SCALE ⅜"=1 FOOT
GRANITE
SAND
CONCRETE: PORTLAND CEMENT 1 PART. TORPEDO SAND 3 PARTS. CRUSHED STONE 6 PARTS.
A
A
B
B
9"
9"
SEE NOTE
1'-6"
LONGITUDINAL SECTION
AT C-C
SCALE ⅜"= 1 FOOT
SEE NOTE FOR SPACING OF TIES

NOTES:

OUTSIDE RAILS TO BE ¼" LOWER THAN INSIDE RAILS.

PAVEMENT TO BE GRANITE BLOCK AS SPECIFIED IN ORDINANCE FEB 11TH 1907, UNLESS OTHERWISE ORDERED.

ON CABLE CONSTRUCTION SPACE TIES SAME CENTERS AS CABLE YOKES.

ON ALL OTHER WORK SPACE TIES ON 4'-0" CENTERS.

PAVEMENT TO BE SWEPT WITH DRY GRAVEL ONLY.

Fig. 1.—Track Construction with Steel Ties.

railway track construction. The grooved girder rail used is specially designed to meet the requirements of the "Municipal Code of Chicago" (which specifies that, "grooved girder rails shall be used in the streets"), and to provide a rail of that type that would give as great a life as possible under the traffic conditions of this City.

It is the purpose of this paper to describe the different types of track construction adopted, the theory upon which the designs are based, and an explanation of the use of the different materials employed to carry out the theory, with the hope that it will bring out a thorough discussion of the subjects.

Theory of Design: The principle object sought by the design of track construction submitted herewith was permanency of construction with minimum maintenance, depreciation and renewal expense. Inasmuch as the rails and joints of a track are subject to direct and continuous wear and must in time be renewed, the track has been divided, possibly arbitrarily, into what we term a "superstructure" and a "substructure." That part of the track that must be renewed being styled the superstructure, consisting of rails, joints, and possibly the tie fastenings; and that part of the track not subject to direct wear, or necessarily affected by the operation of renewing the superstructure, has been styled the substructure, consisting of ties, ballast, etc. (The subject of paving will not be referred to here in detail, as pavement is considered to be a separate item.)

From the brief description given above it will be seen that the theory of our track construction consists of a permanent substructure that will not depreciate and a superstructure that can be renewed when necessary without disturbing the substructure. There has been developed and approved by the Board of Supervising Engineers three types of track, each type differing from the others in the character of the substructure and tie fastenings. These types are as follows:

Type No. 1: Consists of a concrete foundation with steel ties, spaced four feet, center to center, entirely embedded in concrete, and with a specially designed renewable clip and wedge for rail to tie fastening.

Type No. 2: Consists of a concrete foundation with wood ties, spaced four feet, center to center, entirely embedded in concrete, and with tie plates and screw spikes for rail to tie fastening.

Type No. 2-A: Same as Type No. 2, excepting that the ties are spaced three feet, center to center.

Type No. 3: Consists of a rolled, broken stone foundation, with wood ties, spaced two feet, center to center, and with tie plates and screw spikes, for rail to tie fastening.

Careful study and thorough discussion were given to the subject of track substructure by the Board. In some cities a type of track

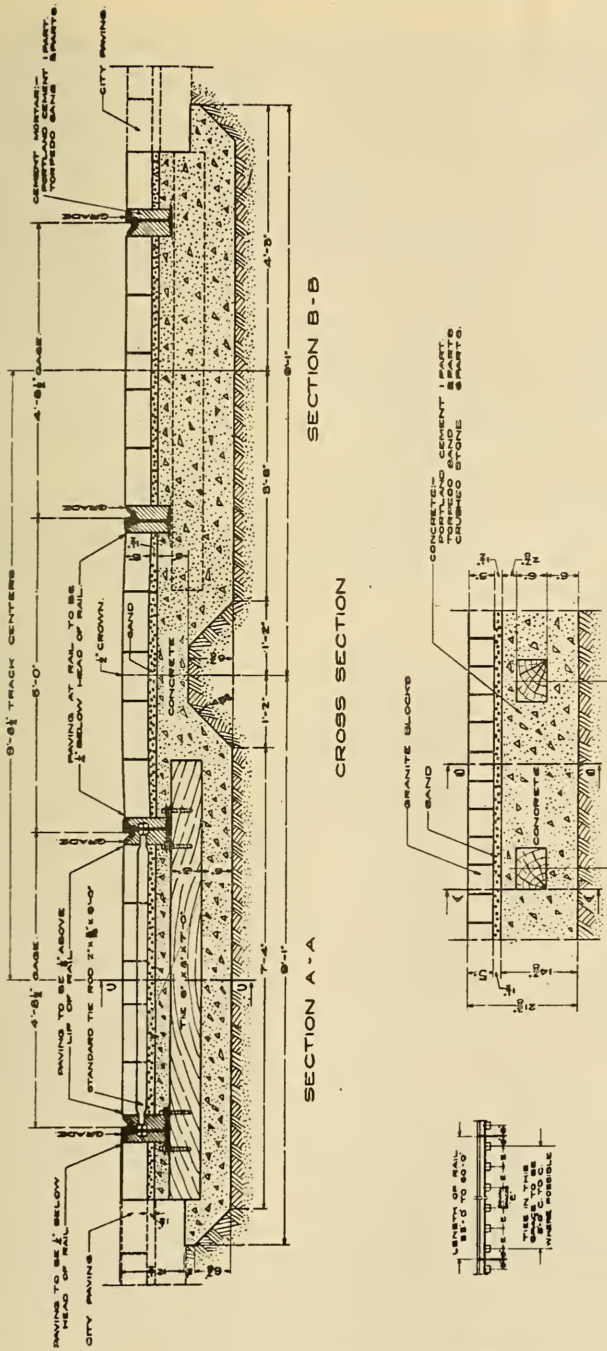

CEMENT MORTAR:- PORTLAND CEMENT 1 PART. TORPEDO SAND 2 PARTS.
CITY PAVING
GRADE
4'-8½" GAGE
9'-8½" TRACK CENTERS
5'-0"
PAVING AT RAIL TO BE ½" BELOW HEAD OF RAIL.
½" CROWN.
SAND
CONCRETE
4'-3"
8'-6"
9'-1"
1'-2"
7'-4"
SECTION B-B
CROSS SECTION
SECTION A-A
PAVING TO BE ⅛" ABOVE LIP OF RAIL
STANDARD TIE ROD
TIE 6"x8"x7'-0"
PAVING TO BE ½" BELOW HEAD OF RAIL
CONCRETE:- PORTLAND CEMENT 1 PART. TORPEDO SAND 3 PARTS. CRUSHED STONE 6 PARTS.
GRANITE BLOCKS
SAND
CONCRETE
5'-0"
LONGITUDINAL SECTION C-C
LENGTH OF RAIL
TIES IN THIS SPACE TO BE 2'-6" C. TO C. WHERE POSSIBLE

Fig. 2.—Wood Ties in Concrete.

construction known as "Beam Construction" has been used, where the rails have been laid in concrete with an increased amount of concrete directly under the rail forming what is termed the "Beam." In some instances without ties, and, in other cases, with the ties at joints and centers or joints, centers and quarters, to assist in surfacing and lining the track. Unsatisfactory results have generally followed the use of this type of construction.

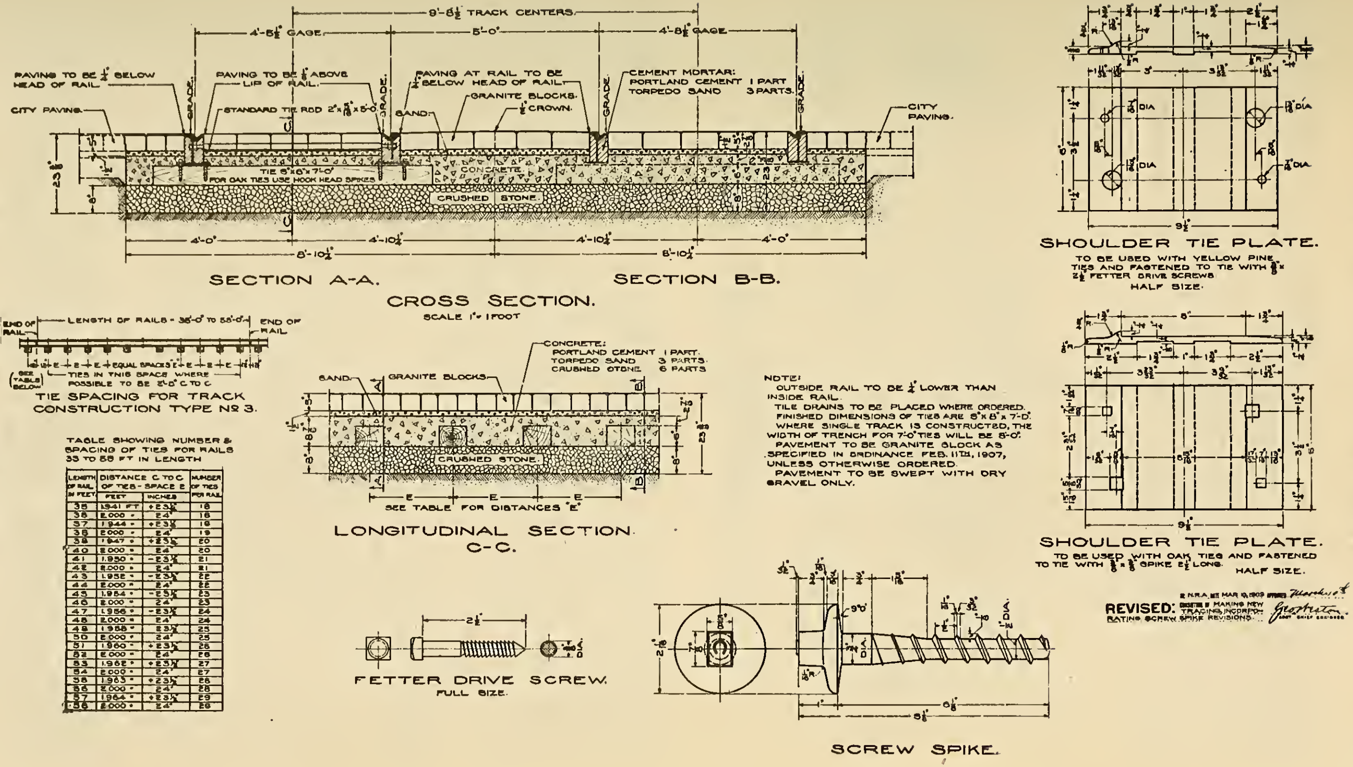
Track has been constructed in the cities of Montreal and Toronto, Canada, where "T" rails and also girder rails have been laid on a concrete foundation without ties, no attempt being made to fasten the track down. The concrete foundation is first laid and the rails are strung out upon it as they would be upon a floor, spliced, tie rods placed, lined, surfaced, grouted and paved. The writer rode over track in these cities that was constructed in this manner and which had been operated about one year, and was, at that time, in apparent good condition with no evidence of failure.

Independent sets of bolt fastenings were considered as a substitute for ties, to be set into the concrete "foundation bolt" fashion, a separate line for each rail spaced four or five feet center to center. This type of fastening has not been used, the type with cross ties being considered better construction, and it is shown here simply to illustrate the text.

The subject of the use of ties in track construction was given thorough study and consideration, and it was the final unanimous opinion of the Board that it was of prime importance to have the rails in the track, tied together independent of the concrete, and the use of ties was, therefore, determined upon.

The substructure in Type No. 1 track, has the elements of permanent life, to-wit: Steel ties embedded in Portland cement concrete. The fact has been quite thoroughly established that steel embedded in concrete is protected from corrosion, and therefore, permanent life can be expected from Type No. 1 foundation, if motion can be prevented between the tie and the concrete, which otherwise would tend to cause disintegration of the concrete and consequent failure of the foundation. While, with the use of steel ties, all members of the Board were of the opinion that the resulting foundation contained the elements of permanency as regards materials, the question of rigidity of the track and the presence or absence of sufficient resilience or cushioning effect to absorb shock and vibration was discussed at length, with the final result that the use of wood ties in Type No. 2 or Type No. 2-A track, meets with more favor, and today Type No. 2-A is practically the standard track adopted by the Board.

It is only practicable to build track with a concrete foundation when conditions are such that traffice will not be put upon it for a sufficient length of time to permit the concrete to become properly set. This can be done when long stretches of track are to be built and provisions can be made for re-routing the cars, or the con-


9'-8½" TRACK CENTERS.
4'-8½" GAGE.
5'-0"
4'-8½" GAGE.
PAVING TO BE ¼" BELOW HEAD OF RAIL.
CITY PAVING.
PAVING TO BE ⅛" ABOVE LIP OF RAIL.
STANDARD TIE ROD 2"x⅜"x5'-0"
GRADE.
SAND.
PAVING AT RAIL TO BE ¼" BELOW HEAD OF RAIL.
GRANITE BLOCKS.
½" CROWN.
CEMENT MORTAR: PORTLAND CEMENT 1 PART TORPEDO SAND 3 PARTS.
CITY PAVING.
TIE 6"x8"x7'-0"
FOR OAK TIES USE HOOK HEAD SPIKES
CONCRETE.
CRUSHED STONE.
23⅝"
6"
4'-0"
4'-10¼"
4'-10¼"
4'-0"
8'-10¼"
8'-10¼"
SECTION A-A.
SECTION B-B.
CROSS SECTION.
SCALE 1" = 1 FOOT
END OF RAIL
LENGTH OF RAILS = 35'-0" TO 58'-0"
END OF RAIL
(SEE TABLE BELOW)
EQUAL SPACES E
TIES IN THIS SPACE WHERE POSSIBLE TO BE 2'-0" C TO C
TIE SPACING FOR TRACK CONSTRUCTION TYPE NO 3.
CONCRETE: PORTLAND CEMENT 1 PART. TORPEDO SAND 3 PARTS. CRUSHED STONE 6 PARTS
SAND
GRANITE BLOCKS
CRUSHED STONE.
SEE TABLE FOR DISTANCES "E"
LONGITUDINAL SECTION. C-C.
FETTER DRIVE SCREW. FULL SIZE.
2½"
SCREW SPIKE.
6⅛"
8⅛"
90°
SHOULDER TIE PLATE.
TO BE USED WITH YELLOW PINE TIES AND FASTENED TO TIE WITH ⅝"x 2½" FETTER DRIVE SCREWS
HALF SIZE.
9½"
SHOULDER TIE PLATE.
TO BE USED WITH OAK TIES AND FASTENED TO TIE WITH ⅝"x⅝" SPIKE 6½" LONG.
HALF SIZE.
9½"
REVISED: MAKING NEW TRACING, INCORPORATING SCREW SPIKE REVISIONS.

NOTE:
OUTSIDE RAIL TO BE ¼" LOWER THAN INSIDE RAIL.
TILE DRAINS TO BE PLACED WHERE ORDERED.
FINISHED DIMENSIONS OF TIES ARE 6"x 8"x 7'-0".
WHERE SINGLE TRACK IS CONSTRUCTED, THE WIDTH OF TRENCH FOR 7'-0" TIES WILL BE 8'-0".
PAVEMENT TO BE GRANITE BLOCK AS SPECIFIED IN ORDINANCE FEB. 11TH, 1907, UNLESS OTHERWISE ORDERED.
PAVEMENT TO BE SWEPT WITH DRY GRAVEL ONLY.

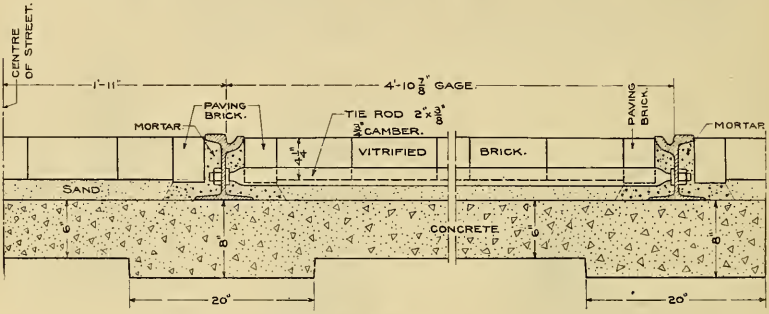
TABLE SHOWING NUMBER & SPACING OF TIES FOR RAILS 35 TO 58 FT IN LENGTH

LENGTH OF RAIL IN FEET	DISTANCE C TO C OF TIES - SPACE E		NUMBER OF TIES FOR RAIL
	FEET	INCHES	
35	1.941 FT	+23¼"	18
36	2.000 "	24"	18
37	1.944 "	+23¼"	19
38	2.000 "	24"	19
39	1.947 "	+23¼"	20
40	2.000 "	24"	20
41	1.950 "	-23½"	21
42	2.000 "	24"	21
43	1.952 "	-23½"	22
44	2.000 "	24"	22
45	1.954 "	-23½"	23
46	2.000 "	24"	23
47	1.956 "	-23½"	24
48	2.000 "	24"	24
49	1.958 "	23½"	25
50	2.000 "	24"	25
51	1.960 "	+23½"	26
52	2.000 "	24"	26
53	1.962 "	+23½"	27
54	2.000 "	24"	27
55	1.963 "	+23½"	28
56	2.000 "	24"	28
57	1.964 "	+23½"	29
58	2.000 "	24"	29

Fig. 3.—Wood Ties on Broken Stone.

Therefore, it became necessary to design a type of track that could be used for emergency, special work, unimproved streets, etc., and Type No. 3 has been adopted for such uses.

Materials: The steel tie used in Type No. 1 track is an "I" beam shape, weighing 14.5 lbs. per foot with one wide flange and one narrow flange. We use the tie inverted—that is—with the wide flange up to receive the rail.



CROSS SECTION.
7" GIRDER RAIL ON CONCRETE.
THE TORONTO STREET RAILWAY CO.

Fig. 4.

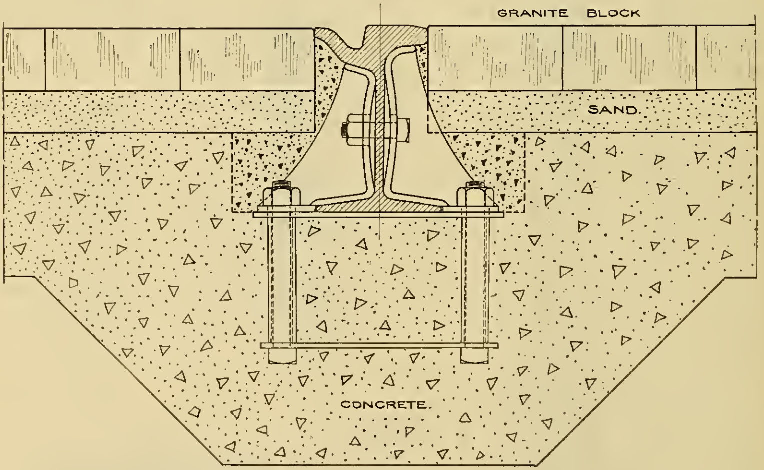
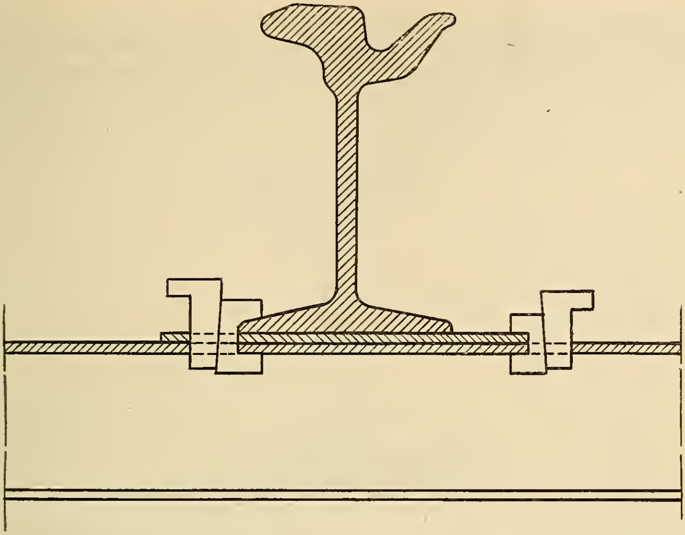


FIG A
ANCHOR BOLT TYPE.
CONCRETE TRACK CONSTRUCTION.

Fig. 5.

struction of a temporary track for their operation. Also, in the placing of special work, such as frogs and crossings, it is impracticable to attempt to use this type of foundation, and a concrete substructure should have a solid foundation of soil under it.



RAIL AND TIE PLATE FASTENINGS
STEEL TIE CONSTRUCTION.

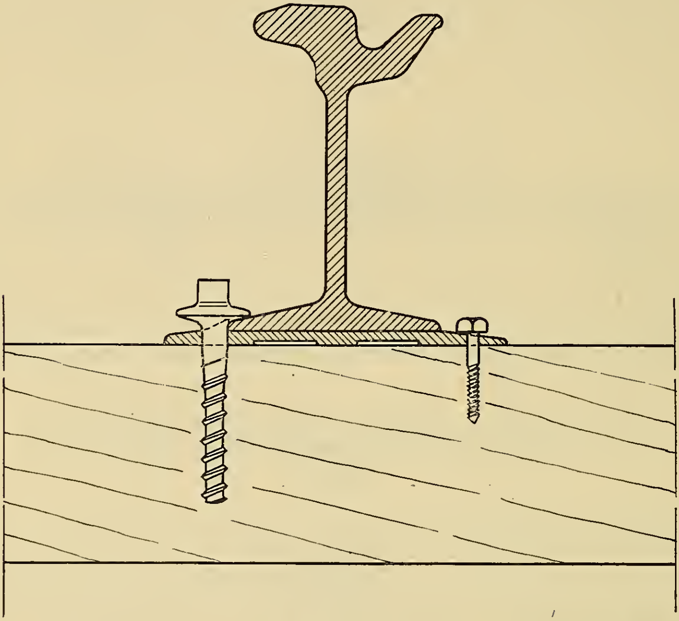
Fig. 6.

According to the theory of our construction, the tie becomes a part of the permanent substructure and must be protected from wear, and necessarily must not be disturbed in the operation of renewing the rails. A tie plate and "clip" fastening were designed (Fig. 6) to accomplish this result. By the use of special fastenings, independent of the rail fastenings, the tie plate becomes a part of the tie; *no movement* can take place between the tie plate and the tie, thereby protecting the tie from wear.

These tie plate fastenings are so designed that, at the time the rail is renewed, the tie plate can also be renewed without disturbing the tie. The rail is fastened to the tie plate and tie by a clip that can be removed and replaced without disturbing the tie.

The wood tie used in Types No. 2, No. 2-A and No. 3 track is 6 in. by 8 in. by 7 ft. 0 in. long, treated with chloride of zinc. In considering the use of the wood tie the subject of decay and methods of treatment for the preservation of the wood were considered. From information gathered, it was believed that timber incased in concrete would be preserved against decay, and our first specification for the manufacture of ties called for untreated, 90% heart, yellow pine ties.

The question of the life of the wood tie has direct bearing upon the length of life of the substructure. It being such an important factor the study of treatment of ties by preservatives was continued, and, after further discussion, it was the unanimous opinion of the Board that the treatment of the wood ties by a preservative would be an added insurance against their decay sufficient to warrant such additional expense that might be incurred by the use of treated ties. After a very exhaustive study of the subject, it was the conclusion of all members of the Board that where ties or timber are exposed to the action of the elements and subjected to rains and floods, the creosoting treatment was preferable, but for our use in street railway track, where the ties are encased in concrete and protected from the action of water, and with no opportunity for the soluble salt to be "leached" out of the timber, the chloride of zinc treatment was all sufficient and would preserve the ties against decay. Therefore, the standard tie as now used in the track construction is the chloride of zinc treated tie.



RAIL AND TIE PLATE FASTENINGS
WOOD TIE CONSTRUCTION.

Fig. 7.

The treatment of ties with a preservative, permits the use of a wider range of soft woods, and our specifications for treated ties include the following timbers: "Long Leaf Yellow Pine, Short Leaf Yellow Pine, Loblolly Pine, Black Gum, Norway Pine, Oregon Fir, Cypress or Selected Red Oak." *

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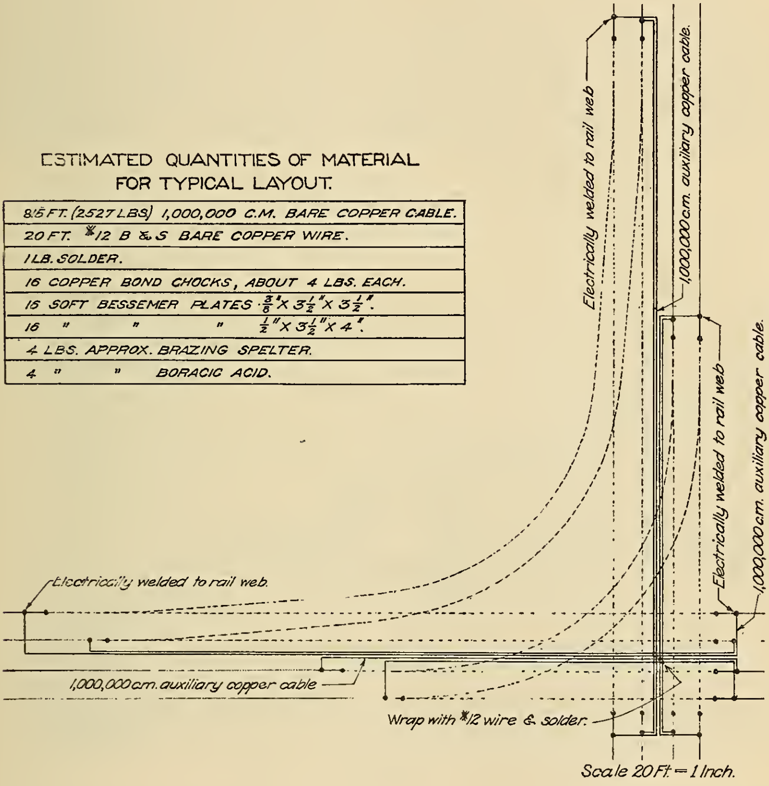
*Since the paper was read, Black Gum has been Omitted from the specifications for the treatment of ties, and Beech and Elm have been added.

The specifications for the antiseptic treatment of ties, covers the treatment by straight creosote and a combination treatment of zinc chloride and creosote, as well as the chloride of zinc treatment. The specifications require the treatment to be applied in retorts or cylinders properly arranged for a steaming, vacuum and compression process.



ESTIMATED QUANTITIES OF MATERIAL FOR TYPICAL LAYOUT.

815 FT. (2527 LBS.) 1,000,000 C.M. BARE COPPER CABLE.
20 FT. *12 B & S BARE COPPER WIRE.
1 LB. SOLDER.
16 COPPER BOND CHOCKS, ABOUT 4 LBS. EACH.
16 SOFT BESSEMER PLATES $\frac{3}{8}$"X $3\frac{1}{2}$"X $3\frac{1}{2}$".
16 " " " $\frac{1}{2}$"X $3\frac{1}{2}$"X 4".
4 LBS. APPROX. BRAZING SPELTER.
4 " " BORACIC ACID.

Electrically welded to rail web
1,000,000 c.m. auxiliary copper cable.
Electrically welded to rail web
1,000,000 c.m. auxiliary copper cable.
Electrically welded to rail web.
1,000,000 c.m. auxiliary copper cable
Wrap with *12 wire & solder.
Scale 20 Ft. = 1 Inch.

NOTE:

All internal standard joints of special work bonded with 40" *2/0 copper bond $\frac{3}{4}$" terminal.

Connect auxiliary cables to special work cables at crossing.

Fig. 8.

Our specifications provide that in the steaming treatment the temperature must not exceed 250 deg. Fah., and that the vacuum applied shall not be less than 26 inches of mercury, and the pressure used for impregnating the fluid shall not exceed 100 lbs. per sq. in., but provision is made for increasing this pressure when the creosoting process is used.

The specifications provide that, with the zinc chloride treatment the solution shall carry such percentage of chloride of zinc salt that the mean impregnation per cubic foot of timber, shall be ½ pound of pure chloride of zinc.

It is essential that the wood tie be protected against destruction of the fibre by the action of the rail, producing what is termed a "channeling" effect. From the writer's observation, one of the principal causes for the failure of a concrete foundation track with wood ties has been the failure to protect the tie from abrasion produced by movement of the rail; the rail having been spiked directly to the tie with ordinary hook-head spikes, the spikes pulling out under traffic permits a movement of the rail which performs work upon the tie and destroys the fibre of the wood. In order to protect the tie thoroughly from the action of the rail, the tie plates secured to the tie by "fetter drive" screws; the plates thereby becoming a part of the tie. This tie plate can be renewed wherever the rail is renewed, without disturbing the tie, if it is so desired.

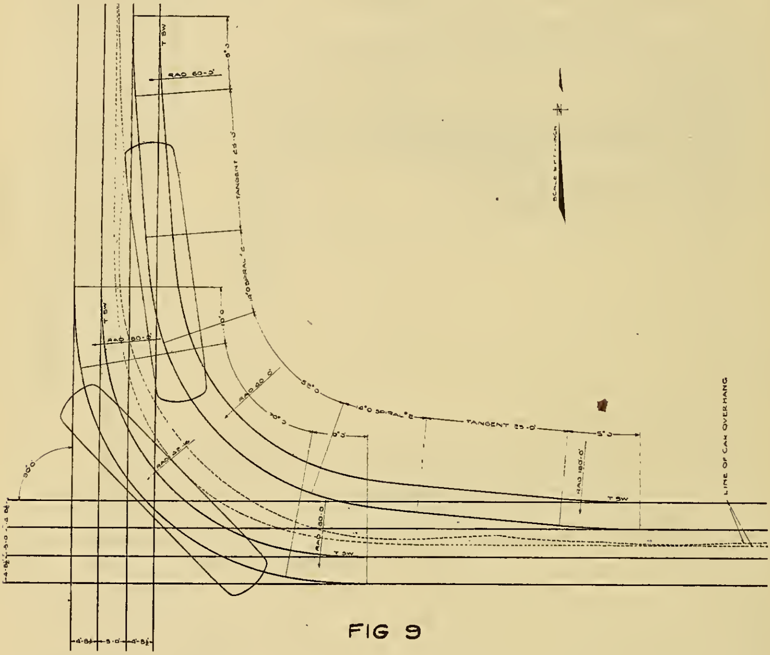


FIG 9

The rail is secured to the tie by screw spikes which are susceptible of being removed or replaced whenever it is desired to renew the rail without disturbing the tie.

To assist in holding the rails to line and gauge, the tie plates are provided with a "shoulder," and tie rods, 5/16 in. by 2 in. with 1 in.

headway, and where the congestion of the streets from vehicular and pedestrian traffic introduces delays to cars, cannot be entirely eliminated in the operation of cars upon the street surface, it is essential that delays from other sources should be reduced to the minimum. Consequently the elimination of delays to cars at curves will be a great factor in reducing the schedule time of the cars.

Owing to the rapid wear of track "special" work at frog and crossing points, particularly when the special work has been "built up" using ordinary rolled rail sections, the question of providing a "maximum wearing" metal to be used in such work has been given much study by the leading special work manufacturers, for the purpose, primarily, of producing a "maximum wearing" metal or a "hardened center" insert at the point of maximum wear, in order to make the life of the special work at these points of "maximum wear" equivalent to the life of the connecting rail, with the result that metals have been produced that outwear the connecting steel rails; and it is very frequently the case in the life of "hardened center" special work that the rolled Bessemer steel connecting rails wear out before the frog point or crossing point.

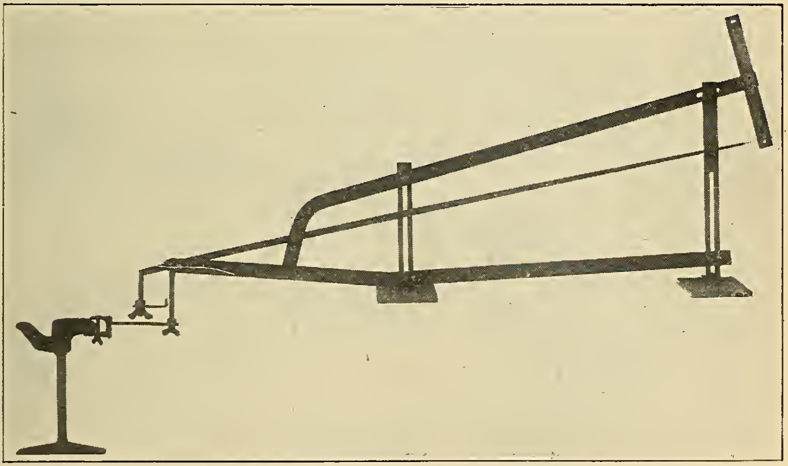


Fig. 11.—Measuring Lateral Deflection.

The metal that has met with the greatest success is a steel alloyed with manganese, which, in its manipulation and annealing, produces a metal that is very hard and tough, but ductile, a metal so hard that it is not subject to rapid wear and is not brittle.

Such special work that wears rapidly is very objectionable by reason of the poor operating condition resulting from deteoriation, and is most expensive from a standpoint of repairs and renewals, for the reason that, by comparison with straight track, the life of special work is short, and not only the cost of the special work round terminals, manufactured from solid bars, are used, spaced six feet, center to center.

The provisions of the ordinances of February 11th, 1907, passed by the City Council of the City of Chicago to the Chicago City Railway Company and the Chicago Railways Company, under which the Board of Supervising Engineers is working, provide under the head of "Bonding" in "Exhibit B" of these ordinances, that "There shall be some form of bonding used which will connect the ends of the rails in such manner that the conductivity of the joints shall be equal to the carrying capacity of the rail." After careful study of the rail joint question the Board of Supervising Engineers concluded that an electrically welded joint would fulfill the ordinance requirements as to conductivity, and with proper protection in the contract covering possible breakages, the joint was considered to be an advantageous one to adopt, and all of the straight track that has been built to date, under the ordinances, has been electrically welded at the joints.

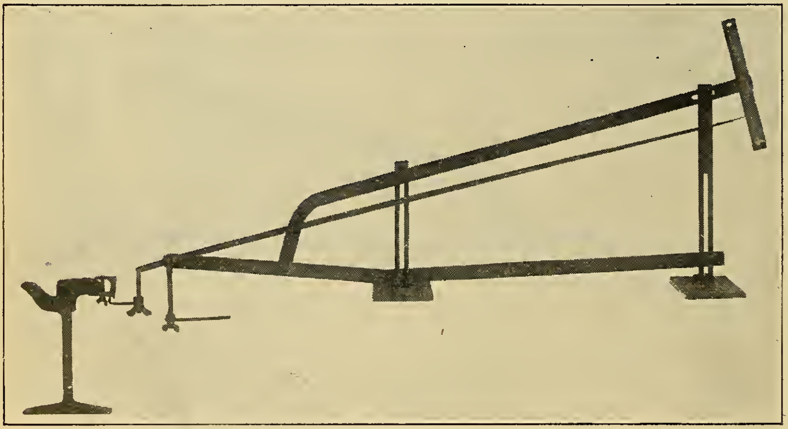


Fig. 10.—Measuring the Vertical Deflection.

On "special work," a bolted joint has been used, and, in order to provide for the continuity of the full conductivity of the rails through the special work, a copper cable is placed under the special work for each rail and its ends are welded to the web of the straight track rail outside of the special work. (These auxiliary copper cables are shown on Fig. 8.) The joints of this special work are bonded with a small copper bond to take care of what might be termed the "internal conductivity" of the piece of special work.

Careful study has been given the subject of track "special" work, and the very important point of providing passing clearances for cars operating in opposite directions on curves has been accomplished. In large cities where cars must be operated under close "layout" is involved, but the cost of removing the old and installing the new work must be considered. Therefore, if, by installing an improved class of special work at a reasonable additional first cost, its life can be increased, it is economy to do so.

In considering the question of special work, the Board of Supervising Engineers desired to design a type that would result in the greatest wearing life possible, and its plans and specifications, in addition to "hardened center" work, provide for switches, mates, frogs, and crossings of solid manganese steel and a large part of the special work that has been installed under the supervision of the Board, particularly upon trunk line, heavy traffic streets, has been of the solid manganese type.

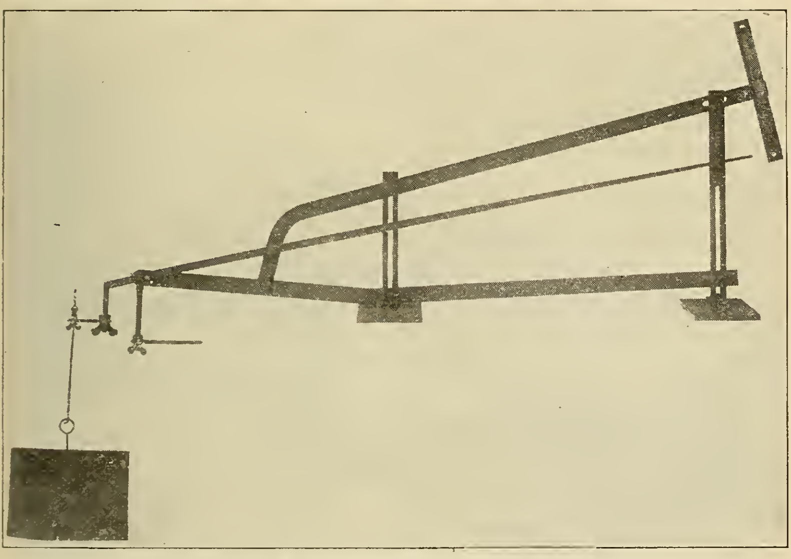


Fig. 12.—To Measure the Tie Deflection.

It has been considered that the concrete in the substructure is one of the most important parts of our track construction, and the specifications covering this part of the work have been drawn very carefully, and, in prosecuting the work, great care has been taken to have first class materials and thorough workmanship in mixing and placing. The specifications provide that the concrete shall consist of, "Portland cement—1 part, sand—3 parts and crushed stone—6 parts"; that the Portland cement shall conform to the "Standard specifications adopted by the American Society for Testing Materials"; "the stone shall be hard, durable and free from dirt, broken and screened and what is known commercially as one inch stone"; "the sand used shall be sharp, clean torpedo sand free from dust, loam and dirt." The specifications cover mixing by hand for emergency, but the mixing of the concrete for the general work is done by machine under the following specification: "The constructor may use a machine mixer at the discretion of the Engineer in Charge. The necessary requirements for the machine will be that the precise and regular proportioning of materials can be controlled, and the product be of the required consistency when thoroughly mixed, and that, if the machine travels upon the track rails, the vibrations and the strains due to moving the mixer will not be sufficient to affect the line and grade of the track."

As stated previously in this paper, the specifications require that the track shall stand fourteen (14) days after the concrete has been placed, before cars are allowed to be operated thereon.

Where the pavement on the outside of the track is asphalt, or of similar character that can be swept and cleaned, the stone and sand are deposited directly upon the clean pavement, but on unpaved streets, or where the pavement is of such character that it cannot be thoroughly cleaned prior to the depositing of the concrete materials, a floor of planking is laid upon the street to receive the concrete materials.

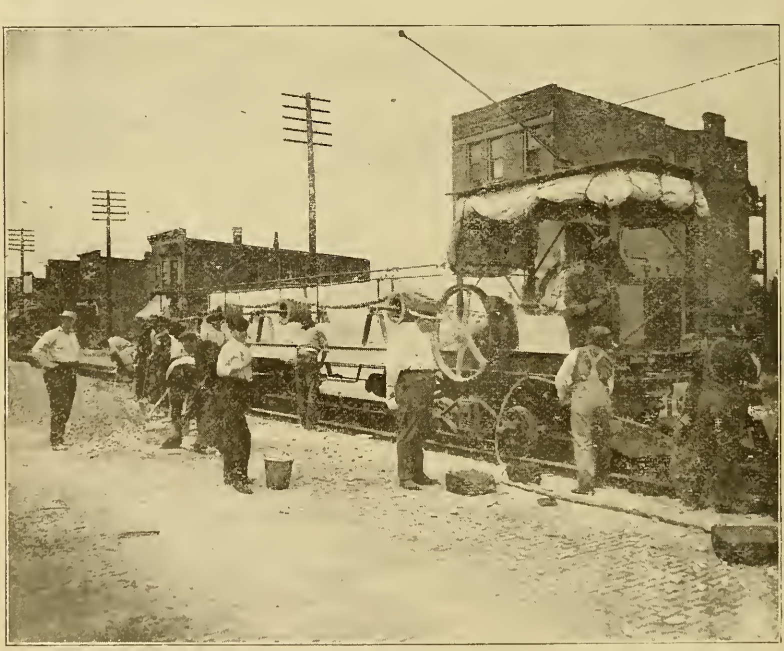


Fig. 13.—Mixing and Placing Concrete in the Track.

The spaces under the heads of the rails and next to the webs are filled with a Portland cement mortar, composed of one (1) part Portland cement and three (3) parts torpedo sand.

In order to provide a thoroughly solid foundation, the trench prepared to receive the track, after having been excavated to the required depth, is thoroughly rolled with a heavy steam roller, and all soft places that are thereby developed are excavated and properly filled with good, clean sand or gravel, rammed, rolled, or puddled as may be directed.

In the case of Type No. 3 track, in addition to rolling the excavation, the crushed stone is thoroughly rolled before placing the ties to receive the rails.

In designing the foundation for Types Nos. 1 and 2 track with the ties four (4) feet, center to center, it was figured that the principal office of the tie would be to hold the rails down and to line and gauge, and that the loads of passing cars would be distributed to the soil by the concrete.

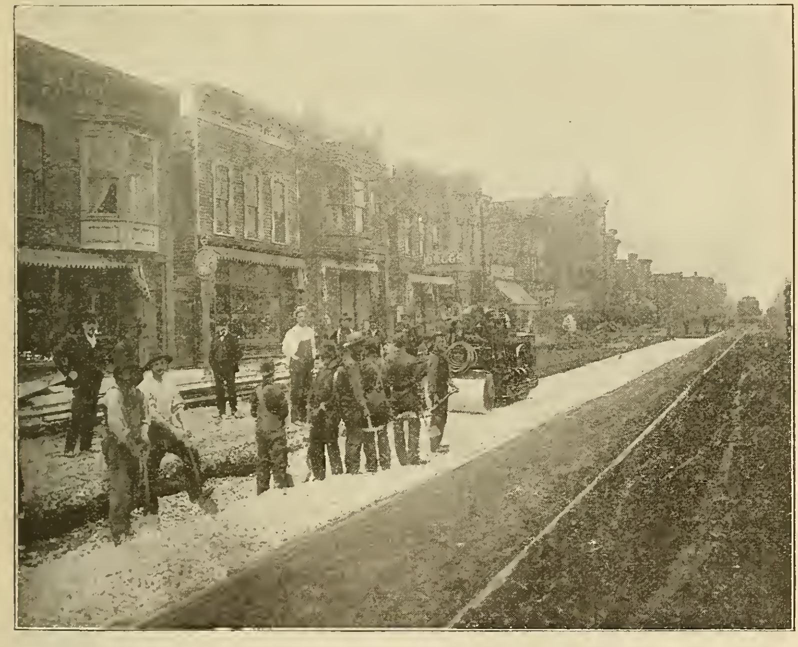
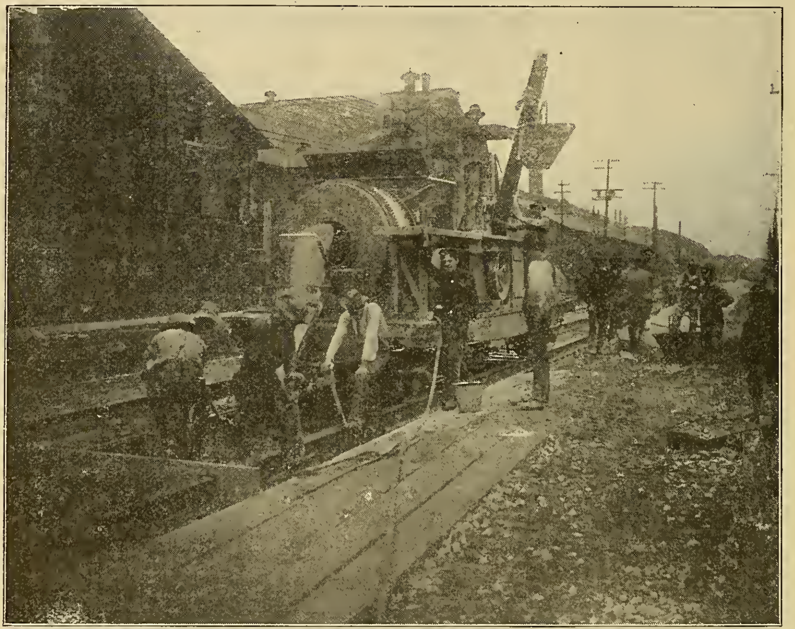


Fig. 14.—Rolling Crushed Stone in the Roadway.

During the year 1907 all wood tie, concrete foundation track constructed was of Type No. 2 design with ties four (4) feet, center to center.

During the winter of 1908 the track built during the previous year was carefully inspected to ascertain its behavior under traffic, and it was found in places that a slight movement in the rail could be detected under the load of passing cars. The Chief Engineer of the Work directed that an investigation be made to ascertain the cause of the movement, to what extent it affected the track construction, and what the possible results might be.

In order to make this study and determine the rigidity and action of the different types of track construction under traffic, observations were taken by means of a "Deflectometer," designed especially for the purpose. (Figs. 10, 11, 12.) This apparatus was so constructed that lateral movement of the rail could be observed as well as vertical deflection, and it was also arranged so that any vertical movement of the ties in the concrete could be readily determined and measured. The principal object of the investigation was to determine if any movement occurred of sufficient magnitude tending to disintregate the concrete foundations, or to endanger the life of the track substructure. It will be observed, by an examination of the illustration that the "Deflectometer" consists of a simple lever mounted on a suitable frame, having at its outer end a pointer which moves over a scale. This lever is proportioned for a ratio of ten to one—that is—the reading on the scale is ten times the actual deflection recorded. The distance from the rail to the fulcrum being four inches, that from the fulcrum to the scale is forty inches. The frame is designed so that the joints of the supporting frame are adjustable to compensate for any inequality in the pavement, so the apparatus can be brought to a true level when the readings are being taken.



Fi.g 15.—Another Concrete Mixer at Work.

In order to segregate the vertical movement from the horizontal movement of the rail a small clamp was made to be attached to the outer side of the rail. This clamp is placed on the under and outer surfaces and highly polished so that the point of contact with the lever will move over these surfaces without friction.

To take readings for vertical deflection the instrument was set at right angles to the track and the frame adjusted to a true level, the clamp applied to the head of the rail, and the short arm brought into contact with the under surface of the clamp. (See Figure 10.) With the instrument in this position it will be seen that any vertical movement that takes place in the rail under load would be transmitted to the pointer at the scale and would be magnified ten times. In this position the instrument records only vertical movement.

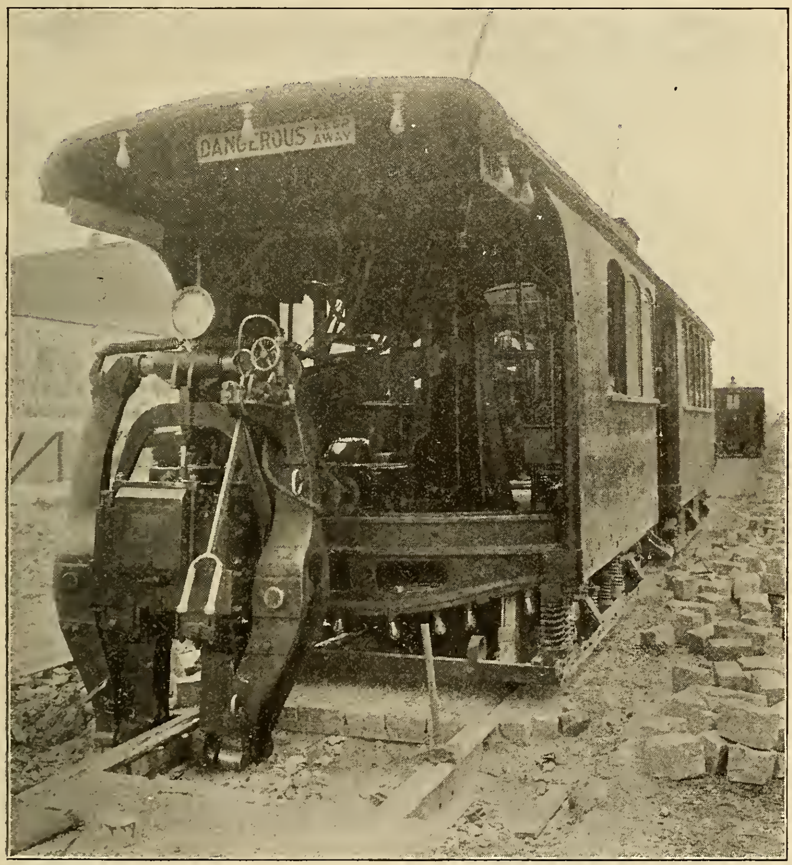


Fig. 17.—Electric Welding Machine

To measure horizontal movement of the rail the other arm is brought into contact with the outer surface of the clamp, and in this position any horizontal movement is transmitted to the pointer on the scale in the same manner as recording vertical movement. When in this position only horizontal movement will be recorded.

To take readings for the deflection of the tie, a longer arm was attached to the apparatus which was fastened to the tie by means of a screw eye when applied to wood ties, and when the observations were being made on steel ties the arm was hooked under the flange.

When readings were taken of the concrete substructure a small hole was drilled into the concrete and plugged with lead, and a small screw eye inserted as in the case of the wood tie.

When these tests were taken it was expected that deflection amounting to as much as from ¼ in. to ½ in. would be found in some places; in this, the results obtained were an agreeable surprise, for the maximum vertical deflection recorded was 5/64 in. In a large percentage of the track tests no vertical deflection whatever was noted. It was also shown by these tests that greater vertical deflection occurred at the rail joints, and decreased away from the rail joints, and that the average vertical deflection observed seemed to be about 1/32 in. No deflection whatever was observed in the concrete, and only in a very few cases was any deflection in the ties recorded. In these few instances the ties were excavated and it was found that the movement was due to improper tamping, leaving voids.

After numerous tests had been made it was determined that practically all movement took place between the base of the rail and the tie plate, and that, in the majority of cases, this movement was observed near the joint of the rails and disappeared entirely as the center of the rail was approached. This can be explained as follows: There is an opening left in the concrete to facilitate the welding of the joint, which is done after the concrete has been placed. When the weld is made the rail fastenings on the ties adjacent to the joint are loosened, and the rail apparently buckles when the weld is made, and, in retightening the fastenings, the rail was not forced back to its original position on the tie plates, and, when the loaded cars passed over the rail at these points the rail was forced down to the tie plate, and, after the load was removed, the rail would spring back again from the tie plate, which accounts for the vertical movement.

It should be noted that horizontal movement was recorded in practically every case of tests made. The average movement in this direction being about 1/64 inch. This horizontal movement seemed to be a constant factor and varied but little in any case. These tests proved that the eye greatly exaggerated the apparent movement of the track under load. It was discovered that, even to the eye of the trained observer, the rails that seemed to have a deflection of ¼ in. in reality did not move more than 1/64 in.

These tests also demonstrated that in many instances where vertical movement of the rail seemed to be observed, it was, in fact, a horizontal movement. The tests further proved that it was impossible for the observer with the naked eye to differentiate between horizontal movement and vertical movement of the rail.

These observations proved (1) that, when the foundation is properly prepared, the concrete properly mixed and placed, and the ties properly tamped, and the concrete given a sufficient length of time to properly set before traffic is allowed upon the track, no movement occurs between the concrete and the soil or between the tie and the concrete, and that, when the fastenings are properly applied, no vertical movement will occur between the rail and the tie plate. (2) The observations proved that the types of construction that are being used in the rehabilitation of the tracks, as far as can be figured at this time, have the characteristics which promise a permanent substructure.

The rehabilitation of the properties of the Street Railway Systems of Chicago makes it possible to carry on work in the largest scale and magnitude, and will entirely change the character of the property and place it, in all departments, on a basis of most modern construction as regards cars and car houses, sub-stations, electrical equipment, track, special work, and transmission system, the latter being placed under ground in a much larger area than has ever before been attempted by any electric traction system operating by means of the over-head trolley.

The improvements now being made in the properties, together with through-routing, and the improvements in operating, including a subway through the business district, which are things we hope will be realized in the near future, will make Chicago's surface transportation equal to the best in the world.

Discussion.

President Allen: Only a few years ago the Street Railway system of Chicago was an eyesore and a disgrace to any city claiming civilization. Recently, however, an experiment has been tried here which marks the beginning of a general era of improvement in matters of that kind—an era in which the street railway systems, instead of being operated solely for private gain, are operated co-operatively, the people having a share in the profits, and also controlling the details of organization, administration, and improvement. We are just beginning to find what a magnificent thing a properly built and operated railway system is. We are beginning to realize in Chicago that surface cars have a usefulness and an adaptability which no other system of transportation can ever entirely displace, and when we come back from visiting other cities we are glad, no matter what else we may miss, to get back to our own street cars and tracks which we are so fond of speaking of as the best in the world.

When this new era was inaugurated in our city, the rehabilitation of the existing street car systems was placed in the hands of a Board of Supervising Engineers, a body with large powers and representing all parties to the negotiations, and the speaker of the evening, Mr. George Weston, has been an active member of this Board for some years and has had a large share in its work.

H. B. Fleming, M.W.S.E.: Mr. Weston has given you the facts, figures, and some of the reasons which influenced the Board of Supervising Engineers in deciding upon plans which were finally adopted for the reconstruction of tracks in the city of Chicago, and has covered the ground in a way that I am sure will enlighten those who have had the pleasure of hearing him.

We have with us, I notice, quite a number of engineers who have been engaged in the actual work of constructing the tracks according to those plans, and I for one would be much pleased to hear them give their views regarding the plans, and to have them present some of the difficulties they encountered in the reconstruction work, which difficulties have been overcome, and in a way, very satisfactory to the Board of Supervising Engineers.

However, there is one thing I would like to call your attention to, which might be considered a construction detail, but which was given very careful consideration by the Board before the work was started; that is, the method of handling traffic while the work was being done. There are some streets where during the "peak hours" we have a minimum headway of about twenty seconds, with practically no opportunity to build track during the period of maximum traffic, or even during the middle of the day, without providing in some way for diverting this traffic. After considerable study and discussion, three general plans for handling the traffic during construction was agreed upon, and have been followed all through this work, with the result that even on a street like Wabash Avenue, where there is a minimum headway of twenty seconds, the cars actually made better time during the reconstruction of those tracks than they were able to make under normal conditions. So evidently our method of handling traffic during the reconstruction period was successful.

The first plan adopted—the simple one—was for streets where the traffic was light, and consisted of single track operation by means of turnouts and cross-over switches. The second plan consisted in the diversion of traffic to some adjacent street, which we did in some few cases where there was a trolley line less than a quarter of a mile away. We found, however, that in cases where the cars were diverted to trolley lines, even though they were only a quarter of a mile away, the receipts on that line depreciated to such an extent that we considered it advisable to follow the third plan in almost every case. This plan consists of laying what we call a temporary track, which is nothing more nor less than stringing a temporary overhead trolley and laying a third track on the street. This track being a little above the level of the street, it was free from traffic, and so we were really able to make better running time during reconstruction than under normal conditions. I suppose most of you are acquainted with this method, because it was used only recently on Clark Street, and last year during the reconstruction of the Wabash Avenue tracks.

I am glad to have this opportunity to express my appreciation of the aid and cooperation which the city authorities have extended in all of our work of reconstruction. They have helped us in every way possible, and especially the police department in the policing of the streets. In many instances it would have been almost impossible for us to carry on the work of reconstruction if it had not been for this aid.

P. E. Green, M.W.S.E.: It is not the intention of this discussion to criticize in general the work of the Supervising Engineers, as the writer recognizes the great value of the work done by them and the immense difficulties under which they have labored. But in some very important details, and details which will vitally affect the life of the work and its accessories, it seems to me that some advantageous modifications might be made in the designs.

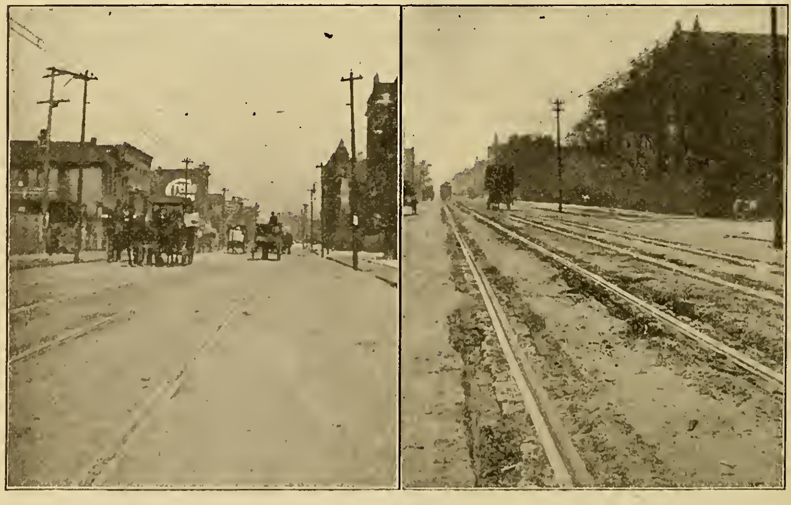
In the rail section adopted, (Fig. 6 or 7) it will be noticed that the outside top edge of the head is beveled off at an angle of about thirty degrees with a horizontal plane. Just what the idea was, the writer does not know, but it probably had some connection with the paving, or possibly with the tread of the wheels. If the pavement is laid at its lower edge, it makes an ugly bump, besides having another objection in the way or drainage, which will be taken up later. This bump will have a disastrous effect on the adjoining pavement, and while Mr. Weston distinctly states that he has not taken up this phase of the traction problem, it is a matter which cannot be separated from the question. Anything that affects the impermeability of the pavement adjoining the rails, will affect the so-called permanent substructure.

To return to the bump; a heavily loaded wagon, weighing say four tons, (and here in Chicago that is nearly a minimum for bulk loads) grinding and sliding off the rail onto the pavement will have a very considerable pounding effect, and a rut is sure to develop sooner or later. If the pavement is laid level with the top of the rail, the V shaped space left, holds water constantly, and this water lying on the track will inevitably disintregate and destroy the pavement. After a rain, or when the street is sprinkled, this little channel of water, lying along the rail, does not evaporate at once. It cannot get away by draining across the pavement. With the most rigid construction, as Mr. Weston's paper shows, there is some vibration. The cars cause this vibration to act like a force pump on the sand bed of the pavement. The vibration, slight as it is, tends to break the bond between the granite blocks and the cement grout filler, which has been used in the construction. In a comparatively short time the sand bed is pumped up through the joints onto the pavement.

This is not a fanciful picture; it may be seen on nearly every street which has been reconstructed for six months. Little cones of sand, like ant-hills, may be found along the rail. As an instance of such action may be cited West Madison St. from the river to Rockwell St. This street of very heavy traffic, both of cars and other vehicles shows plainly this action. In two or three years the pavement adjoining the rail will be in bad condition.

There is one way that this action can be stopped. It is my belief that a mistake was made when cement grout was used as a filler for this brow pavement. It is not the filler for such a situation; as there is no yielding to the vibration; some of the joints will break. But as it is already in place, in order to secure a good result, a few months after the work is finished it should be gone over carefully with a sand blower, the loose joints thoroughly cleaned, and then filled with an asphaltic cement. A properly prepared asphaltic cement has a life of fifteen years, at least; it is elastic, impervious to water, and but little attacked by street liquids.

If this fault is not corrected, what effect will it have on the permanent substructure? It will be admitted that a tight, waterproof, closely laid pavement helps to keep down the vibration. This vibration, however, will never grow less, and must increase as time goes on. But if the increase is accelerated by outside influence, it will certainly reduce the life of the construction. The loosened blocks of the pavement and the grinding sand and water will tend to break up the mortar plastered under the head and against the



Taylor Sreet.

east of Blue Island Ave. west of Blue Island Ave.

web of the rail, and the rail will be that much more free to pound the concrete beneath.

Taylor St., from Canal St. to Blue Island Ave., was paved with creosoted wood block in 1904. The tracks were reconstructed, but the rail section had a square edge, or one nearly so. The blocks were laid level with the rail and tight against it. After five years' service, both track and pavement are in first class condition. Lincoln Ave., paved in 1907-1908, with creosoted blocks laid close against the rail, plainly shows in many places, the effect of this bevel. Altogether, it seems to me, a very strong case may be made against the rail used.

Still more significant are the photographs, (Fig. 16) which shows the creosoted block on Taylor St., above mentioned, which is in a perfect condition to-day, and also Taylor St. from Blue Island Ave. to Paulina St., laid with asphalt *at the same time*, but with a separate granite brow. The tracks are settled about two inches, and, as may be seen, the ruts along the granite are very bad. It might be said that this is the result of the difference between the creosoted pavement and the asphalt; but the asphalt on this whole street is now in fine condition, except along the rails. The whole result is certainly caused by poor and faulty brow construction, or, in other words, the combined action of water and vibration at a point made weak by not being more nearly impervious.

It is not maintained that the reconstruction now is not better than it was in 1904, but if a creosoted wood block pavement laid tight against a rail in 1904, when the reconstruction was not as good as that of to-day, shows up better than a similar pavement laid in 1908, under more approved methods, there must be a fault somewhere, and I think it is in that apparently insignificant bevel of the rail top.

Another point is that in the reconstruction, no matter what kind of a pavement is to adjoin the rail, the concrete shoulder is made approximately seven inches below the top of the rail. This is all right where a granite block is put in, but when a creosoted wood block pavement is the street pavement, it is entirely wrong, and no variation has been made, as far as I know, in the method of construction. The specifications of the City of Chicago call for wood blocks four (4) inches in depth and on one (1) inch of sand. The granite blocks are five (5) inches deep and are on two (2) inches of sand. Thus, if the brow is built of the creosoted blocks against the rail, it is either necessary to use two to three inches of sand on the concrete already put in by the railways, or to try to put a slab of one to two inches of concrete on the concrete already in. Any engineer will recognize the difficulty of doing this last satisfactorily. But if the sand is used to bring the pavement to the grade shown on the plans (one-quarter inch below the top of the rail) the pounding of the street traffic will compress that two or three inches of sand considerably more than the one inch of sand underlying the pavement laid by the City, and in a short time the pavement against the rail will be formed into a natural channel in which the water lies, to the ultimate destruction of the pavement. A good example of this may be seen on Lincoln Ave., south of Belmont. By the time the repaving of Lincoln (following the car track reconstruction) had reached Belmont, the engineer in charge realized this fault and endeavored, in the remainder of the work, to remedy it by raising the grade of the pavement slightly above the rail so that the traffic would not force it down too far. This tends, however, to bring the other fault mentioned (that of water accumulating between the rail and the block) into action, and it is somewhat doubtful if it is any improvement.

It is my belief that if the rail had been made square on that edge, the blocks would have fitted it more closely, the brooming of the edges made a better seal than the present construction, and a longer life insured for the pavement and for the permanent substructure.

Another very unfortunate matter in the reconstruction, is the placing of the special work, such as the crossings, turnouts, etc. While the specifications may state that the concrete be fourteen days old before the cars are operated over the tracks, it is a fact that at crossings and other places where this special work goes in, and where traffic is heaviest and has the most severe effect on the construction, the cars are run and the traffic is uninterrupted while the concrete is being placed; in other words, at the point of severest service, the weakest and poorest work is done. The excuse is, probably, that this cannot be helped, on account of operating necessities. It seems to me, however, that more careful planning, such as making surveys for, and ordering of, such specials in ample time, would have eliminated much of this poor work. The work of the first year may be excused, but in the third year the same condition holds. It must inevitably occur that in a very short time much of this work will become in very bad condition and will be a source of criticism and reproach to the Board of Supervising Engineers.

One of the worst features that has yet come to my notice, and which indicates faulty management somewhere, came to light recently when the Chicago Railways Company applied for a permit to lay a conduit on Lincoln Ave.; this, in spite of the fact that a new pavement costing $200,000 has just been laid, following the reconstruction of the tracks; in fact the pavement is so new that the final estimate has not been issued. It is an absolute impossibility, in my opinion, ever to patch a block pavement and get as good a result as the original.

Another bad feature in the reconstruction work has been the breaking of the welded joints. While it can probably he demonstrated that the percentage of broken joints is very small, still with the immense number of joints to be considered, even a small percentage means quite a large number of broken joints, and every broken joint means a hole in the pavement to start the disintegration. Is it not a question whether the old method of welding joints (that of pouring the molten metal around the joints) is not superior to the method now in use? While here in Chicago our experience with that old way was limited, still there were practically no broken joints, while now there are many.

As before stated, I do not wish to criticize the Board of Supervising Engineers for neglect of details—details which should have been met and worked out by subordinates—but such matters as the clearance between cars and the height of the car step about the street pavement are of such moment that it would seem they could and should have been satisfactorily settled before starting the work. The "death strip" is an appropriate name for the space left between passing cars under present plans. We must admit, however, that even with an ideal arrangement and operation of any railway system, some accidental fatalities must inevitably occur.

The selection of dimensions which left so small a clearance between cars was a mistake, and one which involves the responsibility for great loss of human life, and yet, what will be the result of a change at the present time as advocated by the Chief Engineer of the Board (see the "Chicago Record-Herald" of June 15th, 1909), who claims to have been overruled when he originally recommended a greater clearance? It has been argued in this connection that people once knowing that there was no escape for him who was caught between cars would keep the fact in mind and guard against such danger. If, now as the reconstruction work is over half done, a change is made, how confusing it will be for one not yet versed in mathematics to figure his chances of life in an emergency when he remembers that in some places there are but eight and one-half inches, while in others there are twenty inches between cars. Again, the special work which must be all or nearly all ordered, would be a source of annoyance, to say nothing of expense, and while it may have been satisfactorily demonstrated to the Board of Supervising Engineers that a rail with its base embedded two inches deep in concrete can be removed easily and replaced by a new rail. I am very skeptical about the practicability or economy of trimming out a new bed for the rails in the "permanent concrete substructure," when it is desired to put new rails in a different location for the old ones.

In closing, I wish to thank my friend and colleague, Mr. William W. Marr, M. Am. Soc. C. E., for many suggestions in connection with this discussion and for the photographs which illustrate the text.

E. N. Layfield, M.W.S.E.: I think it might be interesting if some one would tell us something about the electric welding process.

R. F. Kelker, Jr., M.W.S.E.: We obtain the electric power for welding from the trolley wire at about 500 volts D. C. and transform it to about 300 volts A. C., by means of a rotary converter in one of the welding cars, and this alternating current is conveyed

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See Fig. 17, Page 589, for illustration.

to a second transformer placed in the center of the welding jaws, which again steps down the voltage, until we have about 5 volts, with the amperage running above 30,000. A bar is placed on either side of the rail web and they are joined to the web by these electric welds. The first weld, which is made at the junction of the rails, (the joint having previously been shimmed tightly) is an ellipse in shape, and its long axis is vertical. The object of making the first weld at the center is to get the maximum elongation of the bars through heat, and then, after the end welds are made, and the bars become cool, a contraction takes place, which gives a pull at the joint, draws the rail ends together, and gives the effect of a clamp. In making each weld, after the proper temperature is had, which is determined by the eye of the foreman, pressure is applied by means of an hydraulic jack set in the welder jaws, and the weld is compressed in order to work the metal, and obtain a better grain than would result from the simple application of heat.

Mr. Green, in his discussion, remarked that the percentage of failures of joints was probably higher than that due to the older form of welding, or the cast weld. If I am correctly informed, I think Chicago, Milwaukee, and Minneapolis have had the greatest success with cast welding of any cities. In the East cast welding was tried at various times but not with great success, owing to two facts: First, the slipping of one of the rails in the body of the metal cast around the joint, and second, the pounding of the head of the rail under traffic either at the joint itself or immediately adjacent at the end of the cast weld itself, which results in poor surface. Although I might be criticized for saying so, I believe electric welding is superior to cast welding, particularly when applied on rails of 7 in. or more in height; the Standard Chicago rail, described by Mr. Weston, is 9 in. in height.

Mr. Layfield: I would ask whether any distinction is made in the welding process due to the temperature of the atmosphere. In splicing rails for steam railroad, where they are not welded, a greater space is left at the joints in cold weather than in hot weather. The welded rails, if laid in hot weather, would have a greater temperature stress in cold weather than if they were laid in cold weather. Is this recognized in the welding process, or is the process exactly the same, regardless of temperature of the atmosphere,

Mr. Kelker: In the comparison of surface tracks with steam tracks, we have one important fact to consider, and that is the amount of metal exposed to the action of atmospheric temperature, is comparatively small. The rail being embedded, we have not the hot rail we find on a steam road. In the work here we have paid no attention to the expansion of the rails, knowing that the pavement and rail fastenings would keep the rails from buckling. One thing I have observed in regard to the expansion is that the strains in the rail are apparently local.

In New York City, on the underground electric railway, they had considerable trouble in hot weather from the movement of cast welded rails. It has been to such an extent that it forced the "slot" to close, in some instances, so as to bind the "plow" or underground trolley and stop operation. This would be corrected by taking a fire hose and wetting down the street intersection.

In New York City the best success with cast welding was had where the work was done at night and during the cool season of the year. They have had considerable trouble with expansion joints which their engineers believed necessary to use.

Mr. Layfield: Do you conduct the work just the same in summer as in winter?

Mr. Kelker: As no allowance is made for expansion and contraction, the matter of different seasons is not considered.

President Allen: How is the joint assembled before welding?

Mr. Kelker: The rails are first butted together and held by temporary splice bars during construction. The first operation is to remove the temporary splice bars and then sand-blast the rail as well as the weld bars at the points of contact. The bars are 1⅛ in. thick, 3½ in. broad, and 22 in. long. They are placed in position on small brass chucks which will hold them to proper height (the joint having been shimmed by a thin section of the rail), and the welds are made in the order previously stated. After the welding is completed, a grinding machine is used to remove any inequality in the head of the rail, and brings it to a true and finished surface. There has been considerable improvement in the manipulation of the welding process since the work began in Chicago. We had more trouble the first season than we had expected, but we now have a better weld and a marked decrease in the percentage of breakages. This improvement was the result of a series of experiments made by the contractors.

President Allen: How do the breakages in the electric weld joint, such as you are installing at the present time, compare with the best examples of cast joints?

Mr. Kelker: I would say, off-hand, that our highest breakage has been 50% less than the ordinary breakage of cast welded joints. In other words, if we had 5% breakage in electric welded joints, in the same work there would have been 10% or higher in the cast welded joints.

President Allen: What length of rail are you using?

Mr. Kelker: The rails we are installing are 56 and 58 feet long.

C. R. Dart, M.W.S.E.: It seems to me that the area of the splice is much less than the area of the rail, and I should think there must be a variation in temperature of rails of at least 80 degrees between summer and winter, producing considerable stress on the rails. It also seems to me that the area of the weld is less than the area of the spliced rail.

Mr. Kelker: With one or two exceptions no joints failed to show the 100% in conductivity required, and the majority showed considerably over that amount.

Mr. Weston: The majority of breaks—over 90% of them—are outside of the bar and the portion that is welded.

In experimenting with the weld at the testing plant of the Rail Joint Company, after the first year's use of the electrically welded joint in Chicago, in order to improve the character of the weld, there was a great many sections of rails welded and tested with a testing machine, and in almost every instance the rail would break outside of the welded bar, indicating that the rail at the joint is stronger than the rail section itself. These tests also developed the fact that the use of flux improved the joint.

Mr. Kelker: It is a rare instance when you get a break through both bars.

Mr. Sawyer: Does it ever occur that the weld itself breaks—that the bar breaks loose from the rails?

Mr. Kelker: I have never known that to happen.

President Allen: From the standpoint of a structural engineer, I think we should find some weaknesses in the joint. I suppose, however, "the proof of the pudding is in the eating." What experiments were made to determine the life of untreated timber embedded in concrete? Was that determined from data at hand or what evidence did you have to come to your conclusions?

Mr. Weston: I presume all of the members of the Board (I know I did, myself) resorted to all the literature they could find on the subject. We applied to the Division of Forestry at Washington and were flooded with literature on the subject of treatment of timber for the purpose of preservation. I think we nearly exhausted all the points they had to offer. In addition to that we had the aid and advice of Mr. Samuel Rowe, who has spent years in the study of the preservation of timber, particularly in regard to the preservation of ties on steam railroads; also had the advice of Mr. Octave Chanute, who gave us a long discussion of the advantages, etc., of the different methods of preservation of tie timber. We have in our files a package of literature leading up to the final conclusions by the Board, that I should be very glad to turn over to anybody who wishes to go into the subject. But I do not think it would be wise to take time this evening to go further into this matter.

We consider the advice received from Mr. Rowe and Mr. Chanute as important as any we had on the subject, and as a result of our study and discussion, and the information we have received from the gentlemen referred to and others, we concluded, that the chloride of zinc treatment was best suited for our purposes, and would preserve the ties against decay.

S. H. Goodenough: I will make a few comments on Mr. Green's criticism of the method of installing special work. He makes the statement that two weeks' time is required to allow the concrete to set sufficiently to stand traffic. That is true only of Type No. 2 and Type No. 2-A tracks. The special work is all practically Type No. 3 track and is, to all intents and purposes, as far as the question of track is concerned, a completed track before the concrete is put in at all, the concrete merely serving to form a foundation for the paving and protect the ties from moisture. Of course it doubtless helps the life of the work to have that concrete tamped well under the rail, but the prime object of the concrete in this type of track is to support the pavement. Also having traffic on that work while it is being put in, serves the purpose of the steam roller on the straight track work, and tends to settle the sub-grade and the ballast prior to the time the work is finally closed, so we have a chance, after the traffic has been on the work several days, to give it a final lift and tamping before the concrete is put in and the street closed.

Mr. Green suggested that the special work should be secured in advance and put in at the same time as the straight track-work. In a few instances we tried that, and I believe it was found not to work out to any particular advantage. In the first place the curves which are being placed are frequently almost indispensable to the straight track construction gangs for the purpose of getting the material on the streets. If we tear the curves up, we are greatly hampered by the loss of those curves.

Mr. Layfield: I think it would be of a good deal of interest if some of the gentlemen present would give us some information in regard to the progress of the work—for instance, how long it takes to complete a block, or how great a stretch of track can be completed in a certain number of days.

Mr. Dart: I was much impressed with the results of the tests, in view of the great difficulty usually experienced in obtaining true steel castings of this character. I would like to inquire as to what percentage of castings were rejected.

Mr. Weston: In regard to the solid manganese castings. We have had considerable trouble and complaint from the "special" work manufacturers about making perfect castings, preventing warp and other serious defects in casting the large solid crossings. I will say, however, that we have succeeded up to the present time in eventually receiving all the special work layouts complete that the manufacturers have contracted to deliver, and they have passed the inspection of our representatives at the works. I could not say what percentage of castings are rejected, because a large part of the rejected castings never reached our Inspector. While at one factory, where a large part of our work has been built they showed us their junk pile, which was largely made up of manganese castings. Upon inquiry we learned that out of the total number of rejected castings, only three or four pieces had been put up to our Inspector for his inspection. The other pieces were no doubt rejected beyond question and as they came out of the mould the manufacturers decided that they would not do and threw them out on the scrap heap without any hesitation. These are some of the difficulties that are encountered in an endeavor to use the manganese steel solid castings. These difficulties I presume were all appreciated by the manufacturers and largely anticipated. While there has been some criticism of the severity of our specifications, we have had little trouble, and we are getting our work.

President Allen: Is there any appreciable difference in the riding qualities of Type No. 1 or 2 track as against Type No. 3? I understand that Nos. 1 and 2 tracks are on a solid concrete base, and No. 3 track rests on rolled stone.

Mr. Weston: Mr. Fleming is the Chief Engineer of one of our largest roads, and I think if there has been any preference shown for any one style by the operating men, he may have heard of it.

Mr. Fleming: Sometime ago we had that question up for discussion at one of our meetings. At the conclusion of the discussion they took a vote on the question, which resulted in a tie, and they wanted me to decide it. That is about where the matter stands.

Hugo Schmidt, M.W.S.E.: At the time the matter of joints was being discussed, I wanted to ask whether, when breakages occur due to expansion or contraction, the breakage extends into the concrete? As I look at it, the concrete adheres for the entire length of the rail to that portion of the rail which is embedded in it, and any movement of the rail at one point, if there is a break, must affect in some way or another, the concrete.

Mr. Kelker: We have never known of any such breaks. I do not believe the bond between the rail and the concrete is sufficient to resist the horizontal movement of the rail. There has been no fracture in the concrete along with the fracture of the rail, to my knowledge.

President Allen: Mr. Green has raised a question in regard to the 30 degree bevel on the edge of the rail head. Could Mr. Weston or Mr. Fleming tell us anything about that?

Mr. Weston: I should judge, from Mr. Green's remarks, that he is interested, principally, in the question of paving, and, as he correctly stated, paving is an important question in connection with track-work. But, as was set forth in my paper, I believe that the subject of paving is of sufficient importance to make it a separate subject aside from track-work, and in addition the pavement can be macadam, brick, creosoted block, or any of the various types of pavement, and not at all affect the type of track. That is why the subject of paving was not taken up in connection with this paper.

In regard to the small bevel that has been criticised, I presume, from Mr. Green's point of view, it is a proper criticism. The rail was designed to accomplish two things: First, to comply with the requirements of the City Ordinances, which specify a grooved rail. In the second place we have endeavored to design the rail so that it would fill, as completely as possible, the office for which it is put into the street; namely, carry the cars and afford a negative return for the electric current. We also endeavored to design a rail that would give as long a life as possible under the operating conditions. The subject of the life of a rail was a question which it was necessary to go into quite thoroughly at the time of the valuation of the street railway properties, in connection with the passage of the Ordinances of February 11, 1907, and was discussed and argued by three eminent engineers—namely, Messrs. M. E. Cooley, H. B. de Pont, and B. J. Arnold, who were assisted by the minor lights that were fortunate enough to have a part in the discussion.

The life of a rail was figured from the following premise: that a rail was considered to be worn out when the head had been worn down to the point where the flange of the wheel (which is ⅝ in.) would bear on the bottom of the groove, when a grooved rail was used, or on the wagon tread of the rail, when a "tram" rail was used. And this amount of wear was considered the wearing life in the valuation work of the properties. This offered a definite rule for actually measuring the rail depreciation (neglecting the joint) instead of going out on the street and saying, "I *guess* this is 50% and that 25%," etc. The joint depreciation was treated separately. If the rail was in perfect condition at the joint, and in every other way perfect, then the depreciation was figured from the amount of wearing life left in the rail, which was the amount that was left after deducting ⅝ in. from the total height of the head, measured from the bottom of the groove or from the tram.

In designing this new rail, we endeavored to get as much wearing life as we could in the head, and at the same time have a rail that would be practical, as far as the depth of the groove was concerned and other conditions that would affect the ordinary vehicular traffic on the street. Consequently the height of the head is 1¼ in. from the bottom of the groove to the top of the rail, which, I might say, corresponds to the average height of all the modern street railroad rails which have been designated, rolled, and are in use today.

In regard to the small bevel on the back of the rail which has been criticised, I will say that, from Mr. Green's point of view, his criticism is probably well taken, but our plan does not show the pavement outside of the rail to be above the bevel and if the pavement is placed as directed, no groove would exist to collect water. One reason for having the head of the rail a little above the pavement was to create a condition that would as much as possible keep the head of the rail clean. In connection with electric operation, it is very important to have a clean rail. Another reason is that the brow pavement very often comes up. A slightly raised rail prevents the wheel tread from coming in contact with the brow paving which, through frost and other conditions, is lifted up.

In designing this rail we used all the knowledge and applied all the science that we could command in connection with the subject, and I believe, for a grooved type of rail, the design adopted is a good one.

October, 1909

There is another point about raising the rail up that I might mention. A study of the question will show that the groove guard is a little below the top or head, of the present rail. We kept the rail up a little so that the average of the rail and the pavement and all the street conditions would be practically level as the head wears away.

In regard to the failure of the pavement along the rail, and Mr. Green's statement that it might be seen on nearly every street, exaggerates the facts. Failures have occurred in a number of instances, but the great *majority* of pavement has stood up. Our specification for the character of the block, the manufacture, the parallel sides, and everything that pertains to procure a perfect paving-block is an exact copy of the City's specification, issued by the Board of Local Improvements, (except that there is a little variation in the width and length) even to the chemical analysis for the paving pitch. This was done to insure the pavement in the tracks being equally as good as the pavement laid by the City. In endeavoring to get the blocks manufactured, we found that it was a difficult thing to conform to the specifications, and I think Mr. Green will agree with me that it is an utter impossibility to live up to specifications as regards manufacture of paving blocks.

We put Inspectors in the field at the quarries and we believe we are getting the best blocks that are manufactured. I do not think the city inspects its blocks before delivery. We found it necessary to determine what would be a reasonable interpretation of the specifications of the City, covering the manufacture of granite blocks. We could not get paving blocks if we demanded exactly parallel facing, and were obliged to allow an undercut to the stone. The City is getting exactly the same kind of stone, or worse as they do not inspect it at the quarry. We lay our paving as well as it can be laid, but we find this—that it is impossible, with the character of stone and specification requirement for laying the stone, to sweep the joints full of gravel or otherwise to fill the voids with hot pitch. There is a void left in the stone not filled, and the result is water gets underneath the block and the vibration causes the sand and water to churn up, when little bubbles of air will be observed. Mr. Green can see the operations on Wabash Avenue, removing the brow in places where this condition exists, and we are endeavoring to correct it by placing the brow stone on cement grout instead of sand. In place of pouring tar, as provided by the City specifications, we are using Portland cement grout to fill the voids, and I believe that if we were permitted to do it, although the ordinance specifies tar, we should be very glad to use a cement grout for all our pavement instead of tar.

Mr. Green: It is that outside grout pavement, it seems to me, which is the most serious objection to the paving. That is where I claim it would be better to use the tar or asphalt.

Mr. Weston: The result of our observation has been that where we have set the brow block in the cement, in the 1:2:3 sand, and have grout or brow on the outside, it stands, but where we have not done that, we have failed. Mr. Green's suggestion to use asphalt cement instead of tar or grout may have merit and will be considered. But as I said a few moments ago, I do not believe it would be well for me to discuss here, in advance, a subject that is to come up before the Board.

I agree heartily with Mr. Green that asphalt pavement has no place in a street where there are to be street car tracks.

In regard to the "special" work, Mr. Goodenough mentioned the practical points in connection with the disadvantages of endeavoring to place the special work along with straight track work; it is practically impossible, for considering the magnitude of the work, we would never get done.

Mr. Green made the criticism that we have not the plans ready and the special work all on the ground in advance. I wish to say that we have been delayed, probably, more by the Board of Local Improvements in connection with the matter, than any other source, for the reason that we wish to work with them. It is likely they have acted with us as promptly as they could, but it is necessary for us to conduct the rehabilitation of our tracks in the streets at the same time they are carrying on their paving. For instance, we would decide that we would start first on such and such a street. This schedule has been made up in January and February. We could not survey our special work until we knew what tracks were to be rehabilitated, and we could not make our plans until we had all the information.

In regard to the criticism about the centering between tracks, that is another question which I do not care to discuss just now. I will say, however, that the present center between tracks is the standard of the Board, as agreed upon unanimously in the beginning of this work. There have been differences of opinion that have arisen since, and the subject is now under discussion.

I am glad that Mr. Green made his criticisms for that is the object of this paper.

Mr. Gableman: I want to correct one statement that Mr. Weston made in regard to being delayed by the Board of Local Improvements, I think he is mistaken in that.

Mr. Weston: My statement about delay refers to our waiting for information from the Board of Local Improvements regarding the streets they intend to pave, and after receiving this information, we endeavor to make our rehabilitation program fit the Board of Local Improvement's schedule. I will ask Mr. Fleming to say something along this line.

Mr. Fleming: It is our aim, in conducting the work of rehabilitation, to cooperate with the Board of Local Improvements, and I think that on the South Side we have been able to get our work done sufficiently in advance to permit the contractors to go ahead with their contracts without any delay. There are several streets which this Board has asked us to do two years ago on which we completed our work as per request. The contractors have not started yet. I think Mr. Green will bear witness that the Chicago Railways Company has kept ahead of the Board of Local Improvements, and that we have now more streets finished on the South Side than we were expected to do this year.

Mr. Ritchie: I notice that the Board of Supervising Engineers decided in favor of wood ties, in tracks 2 and 3, and steel ties in track 1. It seems that later on they were troubled about the deflection, and they found that the deflection was something like 1/16 in. I do not see the advantage of using wood ties under those circumstances.

Mr. Weston: I do not see any particular connection between the deflection in the track and the cushion effect. Wood we know has the ability to absord shock, but I do not think one need necessarily follow the other. For instance, with the steel tie, where you would not expect any cushion effect, you might have a deflection of the track. I do not wish to combine the two. One thing we wish to avoid is deflection.

Mr. Green: On the No. 3 type of track, what is the use of putting in concrete at all? In other words, why should not crushed stone be better than concrete?

Mr. Weston: We put the concrete in between the ties and on top as a foundation for the paving, for the reason that the use of a little cement and sand is a good thing. That is why we put it in, simply to make a paving foundation. We do not depend on that for the life of our track at all.

Mr. Kelker: In regard to the progress of the work—ordinarily one gang laid one-half mile of track a week. We are now laying a little more than three and one-half miles per week on the North and West Side properties.

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ECONOMIES IN POWER CONSUMPTION IN ELECTRIC RAILWAYS

By N. W. Storer.*

Presented January 25, 1915.

In April, 1912, in a paper before the A. I. E. E. at its New York meeting, Sanuel Insull presented a very strong and convincing argument in favor of large Central Power Stations as against a number of isolated plants. One of his strongest arguments was the enormous saving in fuel that would result on account of the higher efficiency and better load factor with the larger plant. Taken in the aggregate, the figures given were startling and have shown not merely an immense saving in dollars and cents, but a long step towards the conservation of our nation's fuel supply. He estimated that if this system of power generation were adopted for the entire country, it would result in a saving of over 200,000,000 tons of coal per annum—a most stupendous amount. Mr. Insull pointed out that the electric railways in any community would not require more than 15% to 20% of the total power used, but where figures such as that are involved, it is well worth while to try to save even a small part of that percentage; for instance, it is probable that not far from 1,000,000 tons of coal will be burned in Chicago this year to furnish power for the electric railways. Chicago has good reason to be proud of her electric railways, yet I do not doubt that if an entirely new equipment of cars were to be installed with all of the economies that can be introduced with our present knowledge, not less than 40% and possibly 50% of that 1,000,000 tons of coal could be saved every year. Since some of the cars that have been installed on the Chicago surface lines in the last two years have cut the power consumption per car mile by reduction in weight, field control, etc., to less than 67% of that of older cars of the same capacity, it can be seen at once that the above statement is not as wild as it looks.

It is the purpose of this paper to show how some of the savings have been effected and to explain in some detail the possibilities of further economies, especially from the standpoint of the electrical equipment.

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*With the Westinghouse Electric and Manufacturing Co., East Pittsburgh, Pa.

A large part of the energy now consumed, considered in the light of the present knowledge and the best modern practice, is wasted, but on account of the large amount of money invested it will continue to be wasted until the older cars and equipments are worn out. In fact, a great deal of power is still wasted, even in the most modern equipments, if the possibilities are considered.

In taking up the question, there are two things to consider:

1st—The weight to be handled.
2nd—The efficiency of the equipment for handling it.

There is one idea that has been drilled into electric railway men in this country in the last few years to such an extent that it has become second nature to many of them; namely, that every pound of weight on a street car costs the company 5 cents per annum to carry it around. I shall not discuss the correctness of this idea except to remark that the next result of its promulgation has been a nation-wide campaign to cut down weights of cars and equipments. It has, on the whole, produced wonderful results.

A great deal has been done in this respect in Chicago, where the weight of the cars on the surface lines, by careful and scientific design, was cut about 25%. A part of this reduction lies in the use of two motor equipments with maximum tractions instead of four motor equipments. This change would, of course, save a great deal of weight if the same total motor capacity were necessary. A reduction in weight of the entire equipment, however, made it possible to use two 50 H. P. motors where four 40's had been used on the older cars. Moreover, the modern 50 H. P. motor weighs no more than the old 40, so that the two motors on the new cars weigh only half as much as the four motors on the old cars. It is beyond my province to tell how the trucks and car bodies were lightened except to say that it was done by a design that made every pound of material in them perform some necessary function.

After all useless weight had been eliminated, we may turn our attention to the amount of energy required to carry the remaining weight around, how it is all used, and what becomes of it. In other words, we will consider the efficiency of the equipment. The energy consumed by an electric car or locomotive is practically all dissipated in the following ways:

(1) In overcoming train resistance.
(2) In ascending grades.
(3) In motor losses.
(4) In gears and motor axle bearings.
(5) In rheostats.
(6) In auxiliaries.
(7) In brakes.

TRAIN RESISTANCE.

Under this heading is classed all friction due to the motion of the train. It includes friction of the main journals, thrust collars, wheel flanges, rolling resistance on track, air resistance and friction, and in periods of coasting, the friction of motors, gears and axle bearings. It is usually expressed in pounds per ton of train. The importance of train resistance may be judged from the simple formula for power consumption necessary to overcome it. Twice the train resistance in pounds per ton divided by the motor efficiency equals watt hours per ton mile. The train resistance of a street car probably varies on account of local conditions between the limits of 10 and 20 pounds per ton, so that, assuming 80% average efficiency for the motor, the energy required to overcome train resistance varies from 25 to 50 watt hours per ton mile. The total power consumption for street cars usually varies from 120 to 180 watt hours per ton mile, so that probably not more than 25% is used in overcoming train resistance. For elevated and subway service, where runs are longer and many curves encountered, the power required for train resistance is a larger proportion, especially where the speed becomes so high as to give a high air resistance. It can be seen, therefore, that train resistance plays a very important part in the power requirements for an electric railway, and anything that can be done to decrease it is worth while.

Journal friction is one element that can be greatly reduced. This amounts to probably not more than six pounds per ton in average service, but can be practically eliminated by the use of ball or roller bearings. A considerable amount of experimenting is being done and many service tests are being made at the present time with these bearings, and it is probable that before long some form of frictionless bearing will be standardized for main car journals. This will save anywhere from 6 to 15 watt hours per ton mile, and possibly more.

In high speed railroading, the question of air resistance becomes one of considerable magnitude. The resistance offered by the air is due not only to the pressure at the front end but to friction on the sides. The shape of the front end of a high speed car or locomotive has a great deal to do with this train resistance. The front end of a high speed car should be designed to make a hole in the atmosphere through which the car or train could pass without other disturbances of the air than that caused by friction along the smooth lines. Of course it is understood that a car designer has to meet other requirements than that of low air resistance, but this is deserving of much more serious attention than it has yet received in this country. The head resistance of an ordinary car at a speed of 60 m.p.h. amounts to 800 to 1,000 pounds and requires from 110 to 150 kw. to overcome it. Every projection on the car that creates an eddy in the atmosphere increases this amount.

Other elements contributing to high train resistance are bad curves, defective tramming of trucks, unequal diameters of wheels, and any other cause tending to make the wheel hug one rail, producing flange friction. Rapid flange wear is a sure indication of excessive friction on the rail head and an investigation should be made immediately to eliminate the causes of it.

GRADES.

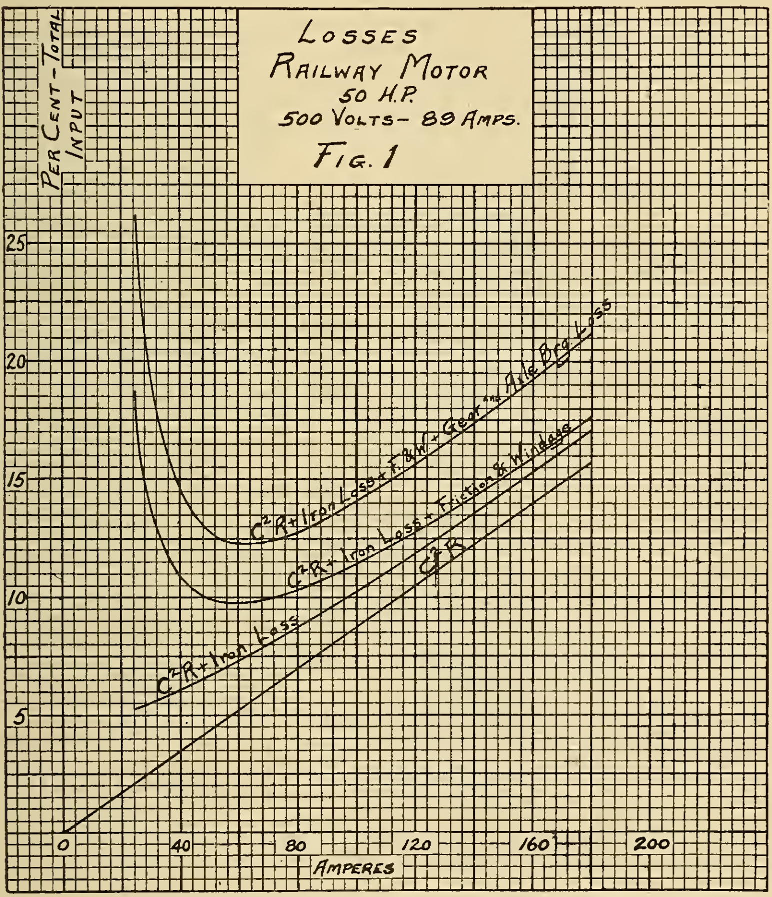
The power required in ascending grades can be decreased only by reducing the weight. It is sometimes possible, however, to save the power stored in the train in descending one grade to help it up the next one. This is seldom done in street car work, but is quite common with lines where long runs are made. Short grades of 1% or 2% on an interurban or elevated line add very little to the power consumption.

MOTOR LOSSES.

The efficiency of a railway motor varies from 80% to 90%, small motors ordinarly used in city service having a maximum efficiency, including gears and axle bearings, of 85% to 86%, while large motors run 2% to 3% higher. The motor losses consist of the I^2R losses in the armature, field windings and brushes; the core loss or loss in armature iron, and pole faces; eddy current losses in bands and armature windings due to rotation in the magnetic field; and friction losses in bearings, brushes and windage. Figures 1 and 2 show the loss curves for two typical railway motors that are used in large numbers. They are standard commutating pole type motors.

Other things being equal, the capacity of a given size of motor is practically dependent upon its efficiency, since the amount of loss determines both the efficiency and temperature rise and the temperature rise determines the capacity. It is therefore pretty certain that the efficiency of railway motors is as high as the state of the art will permit with the present commercial conditions. In any case an increase in efficiency is sure to be accomplished by a heavier and more expensive motor and the increase would be so small as to effect only a minor reduction in the total power consumption. Therefore a full discussion of the matter will not be entered into in this paper. It is desirable, however, to consider briefly the losses due to friction and windage. To show their relative importance I have translated them from watts to train resistance. A motor of 40 to 50 H. P. with ordinary speed characteristics will have approximatety 400 watts friction loss at a car speed of 10 miles per hour; this power translated into train resistance is equivalent to 20 pounds. A two motor equipment would then add 40 pounds to the total train resistance. With a car weighing 20 tons loaded, the armature friction and windage then amounts to 2 pounds per ton. In the same way the axle bearing losses may be translated into train resistance, but owing to the reduced speed of the axle they would probably not amount to more than one-half as much. There are very few data available from which gear and axle bearing losses can be determined, but it is hoped that in the near future further tests will be made which will enable the Standardization Committee of the A. I. E. E. to give more definite figures for the efficiency of axle bearings and gears.

It is possible to use some form of frictionless bearing for armatures, but such bearings, as yet, have not had sufficient test under heavy service conditions to justify their adoption, especially as the cost is considerably higher than that of the ordinary sleeve bearing.

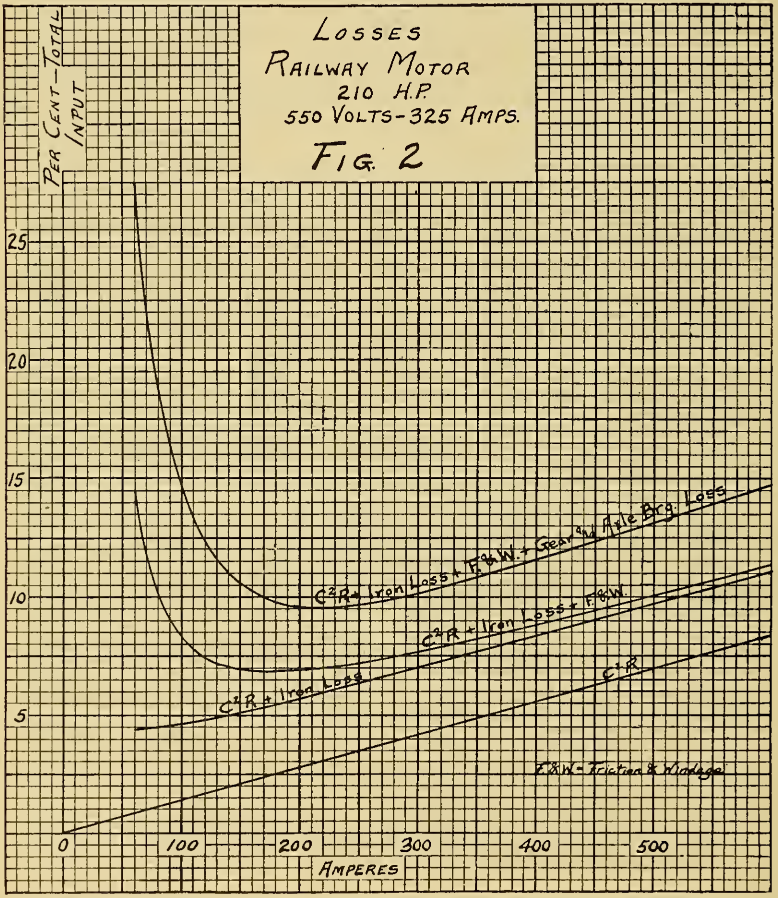


RHEOSTATIC LOSSES.

Everyone deplores the fact that it is necessary to dissipate so much energy in rheostats, but with a constant potential line and commercial motor it is impossible to avoid them altogether. There are various methods, however, by which we can reduce these losses to a much lower amount than has ordinarily been the practice.

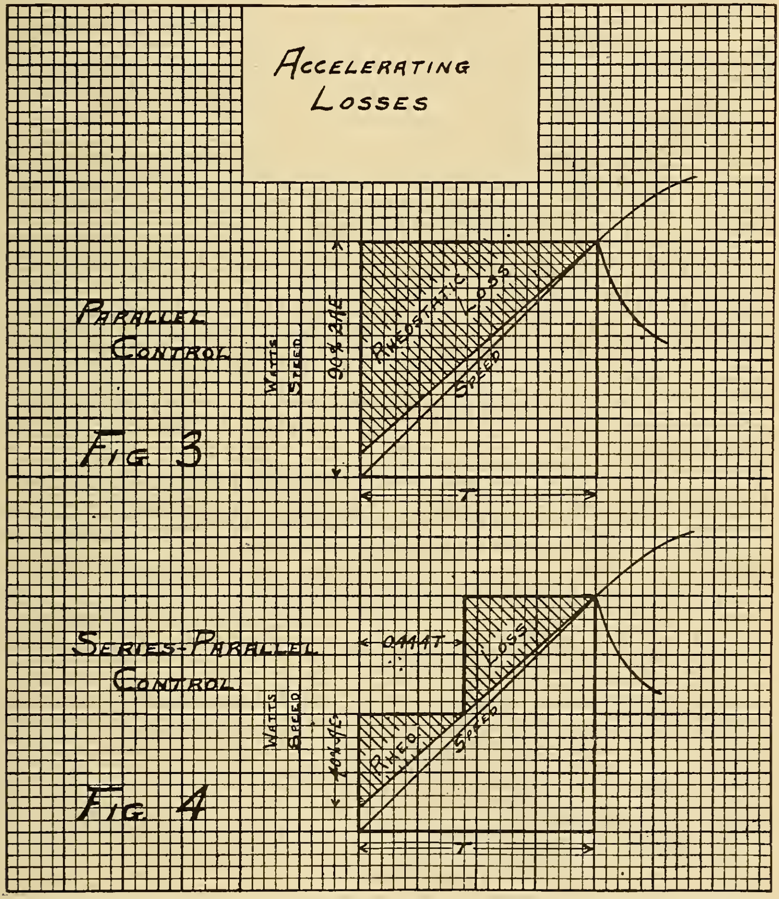
Series parallel control was the first great improvement in this respect. Figs. 3 and 4 show the relative value of rheostatic losses for straight parallel control and for series parallel respectively. Assume two motors accelerating with a current that will give 10% drop in voltage in the internal resistance of each motor, then in Fig. 3, 90% of the voltage will be lost in the rheostat at the instant of starting and an average of 45% during the time the rheostat is in circuit. During the entire time of acceleration double motor current will be taken from the line. With series parallel control

Curve No. 82121



No. 82121

as shown in Fig. 4, the rheostatic loss at starting will be 80% of the line voltage with single motor current, or an average of 40% of the line voltage multiplied by single motor current during the time the car is accelerating in series. The total time will be divided between series and parallel in the ratios of the counter e.m.f's. after the resistance is cut out. In this case it will be in the ratio of 40 to 90 or 44.4% of the time will be spent in series and 55.6% in parallel up to the time the motor curve is reached. When the motors are connected in parallel, the voltage applied to the motor terminals is only 50% of the line voltage, consequently the remainder of the line voltage, or 50%, is lost in the rheostat. The average drop in the rhesostat will be 25% for 55.6% of the time. The rheostatic loss for straight parallel control shown in Fig. 3 may be illustrated in the following formula where *A* is the current for



one motor, T the time to reach the motor curve, and E the line voltage; *Rheostatic loss* $= 2A \times .45E \times T = .90\ AET$. The total power taken from the line during this acceleration is $2\ AET$, and 45% is therefore lost in the rheostat.

In series parallel the rheostatic loss $= A \times .40E \times .444T + 2A \times .25E \times .556T = .456\ AET$.

The total power from the line in this case is $AE \times .444T + 2AE \times .556T = 1.556\ AET$.

The rheostatic loss is thus cut almost in half by using series parallel instead of parallel control, and the total power during acceleration on resistance was reduced by this means over 22%.

The use of four motor equipments makes it possible to go still further and use full series, series parallel and parallel control. This is shown in Fig. 5. The rheostatic loss in this case is the same as in Fig. 4, except for the rectangle cut out by full series operation, the area of which is $.083\ AET$. The total rheostatic loss is thus $(.456 - .083\ AET)$, or $.373\ AET$, a decrease of 18.3% below Fig. 4. The power taken from the line during the time on rheostat is $(1.556 - .083)\ AE = 1.473\ AET$, a reduction of 5.3%. Since the rheostatic loss in ordinary city service is only 12% to 20% of the total power used, it will be seen that the saving resulting from starting with four motors in series will scarcely exceed 2.5% of the total power used, unless there is a great deal of operation at extremely low speeds.

One system which has recently been exploited combines operation with four motors starting all in series, series parallel and parallel with intermediate steps using three motors and a limited amount of rheostatic operation. A portion of the rheostatic losses are eliminated through unequal loading of the motors, due to doubling the voltage on one motor at a time, thus heavily overloading it without a serious surge in the acceleration. A saving of 8% to 10% in power is thus effected.

An inspection of Figs. 3 and 4 soon brings out the fact that the rheostatic loss (other things being equal) varies as the square of the speed at which the motor curve is reached in acceleration. This being true, the characteristics of the motors themselves, and also the rate of acceleration must have a great deal to do with the rheostatic loss. For example, a motor with a steep speed characteristic, geared for a certain schedule speed, will reach the motor curve at a lower speed than one with a flat speed curve geared to the same speed and will therefore have less rheostatic loss. A higher rate of acceleration will also reach the motor curve at a lower speed, especially with an unsaturated motor. This reduces the rheostatic loss in the same way.

The shape of the speed curve has been too often left out of consideration because the unsaturated motor (the one with the steep speed curve) is usually slightly heavier than the saturated motor of the same rating and armature speed, and stress has been laid on the reduction in weight of the motor at the expense of efficient operation. It of course saves power to lighten the car equipment, but if it is lightened at the expense of efficiency the net result may be worse than with a heavier equipment.

Another method of decreasing rheostatic losses is one which was introduced in the early statges of the street railway motor and used extensively with double reduction motors to secure additional running notches on the controllers, which were all of the straight parallel type.

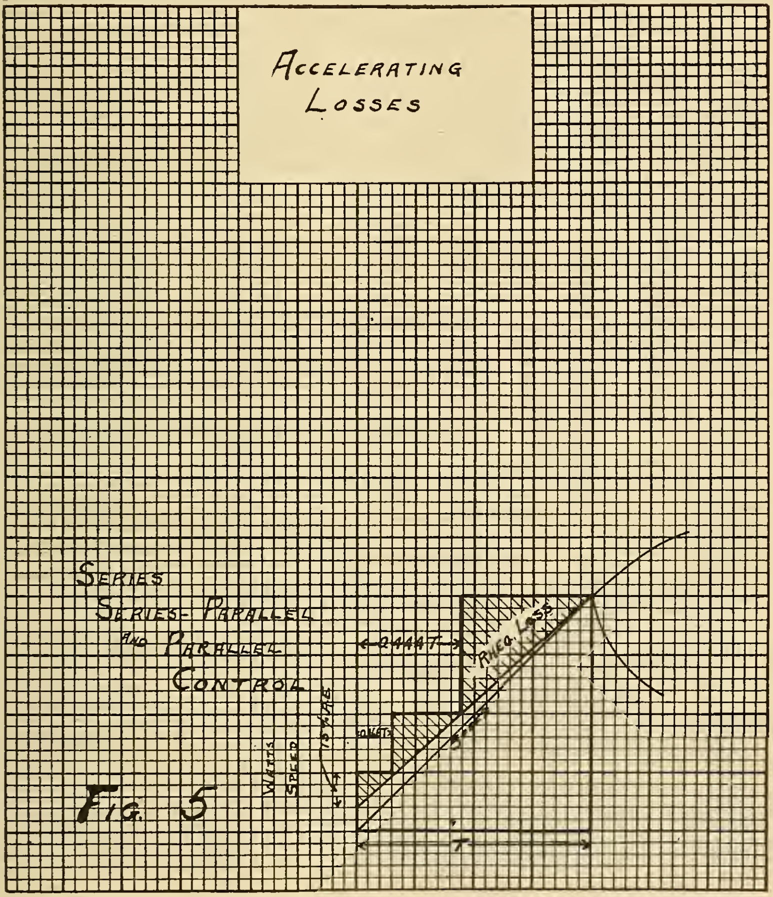


Fig. 5

After the series parallel controller and the single reduction motor were introduced, this control of the field as a means of effecting economical speed variation and reduction of rheostatic losses was dropped because of the trouble from poor commutation and from overloading motors. The commutating pole motor and a better understanding of the application of railway motors to a given service have led to a revival of field control, and it is now used in all classes of service. The use of field control will usually effect a saving of not less than 10% and sometimes as much as 20% in the power consumption. To get the best results the motor should be geared to give the highest speed desired with the short or permanent field. The full field speed curve should be 20% to 25%, or more if possible, lower than the short field speed curve at the accelerating tractive effort. Referring to Fig. 4 and assuming that the full speed of the motor at the accelerating tractive effort is 20% below that of the short field, and that the same rate of acceleration is maintained, a field control equipment would perform

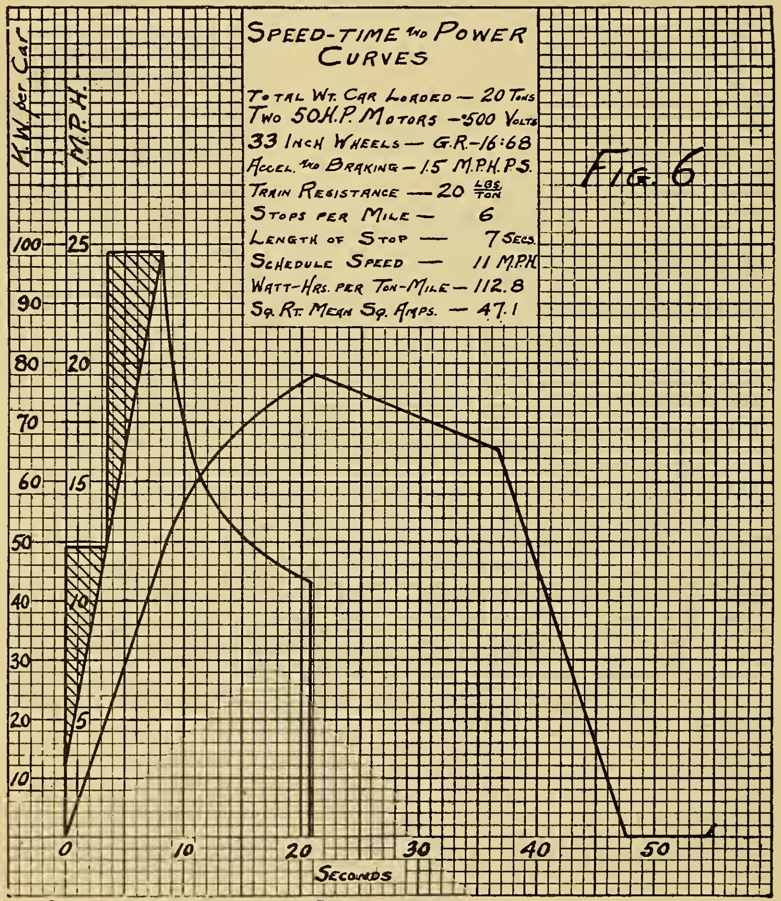


Fig. 6

the service indicated in Fig. 4, with approximately one-half the rheostatic loss. Where the balancing speed on short field is higher than that of the non-field control equipment, a still further saving in power consumption will result on account of the more rapid acceleration on the motor curve permitting a longer coasting period and consequently a lower speed at the time the brakes are applied and less loss in them. Where stops are frequent the use of field control thus effects a very substantial saving in power consumption. Figs. 6 and 7 show speed time curves of typical conditions of service on street railways. Fig. 6 shows the typical run with standard motor without field control, and Fig. 7 shows the same run under identical conditions of load and speed, but with field control. The difference in rheostatic losses is clearly shown.

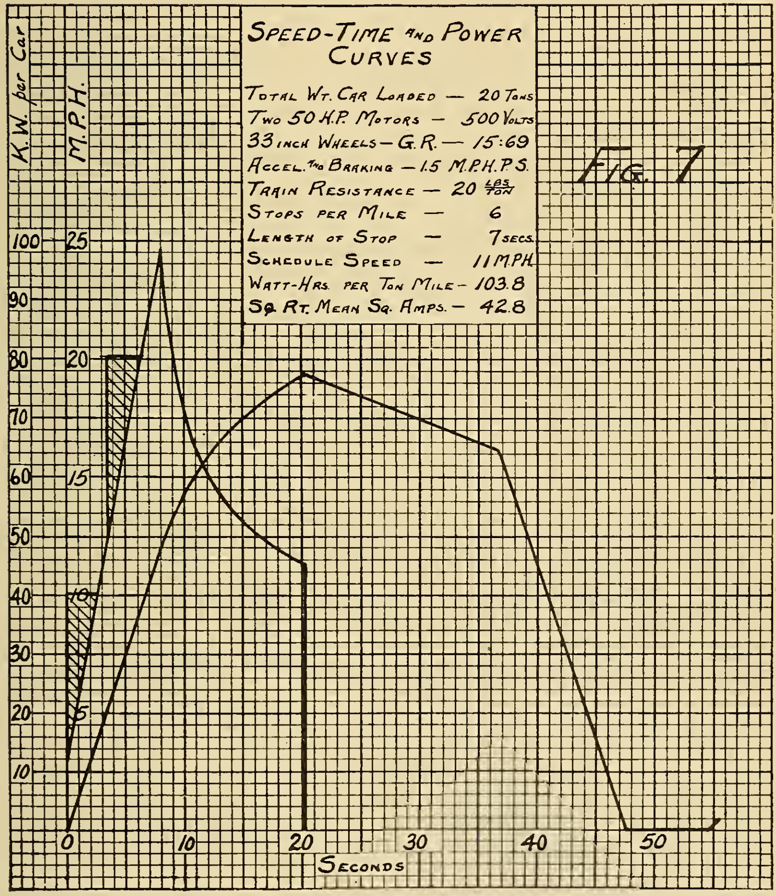


FIG. 7

Fig. 8 shows a set of general curves that may be applied to almost any condition of acceleration on electric railways with reasonable accuracy. The curves are intended primarily to show the rheostatic losses entailed in accelerating one ton under certain conditions of motor efficiency, train resistance and rate of acceleration with and without field control. With these curves are included others showing watt hours input and output or energy used in overcoming train resistance, all plotted in terms of speed at which the motor curve is reached.

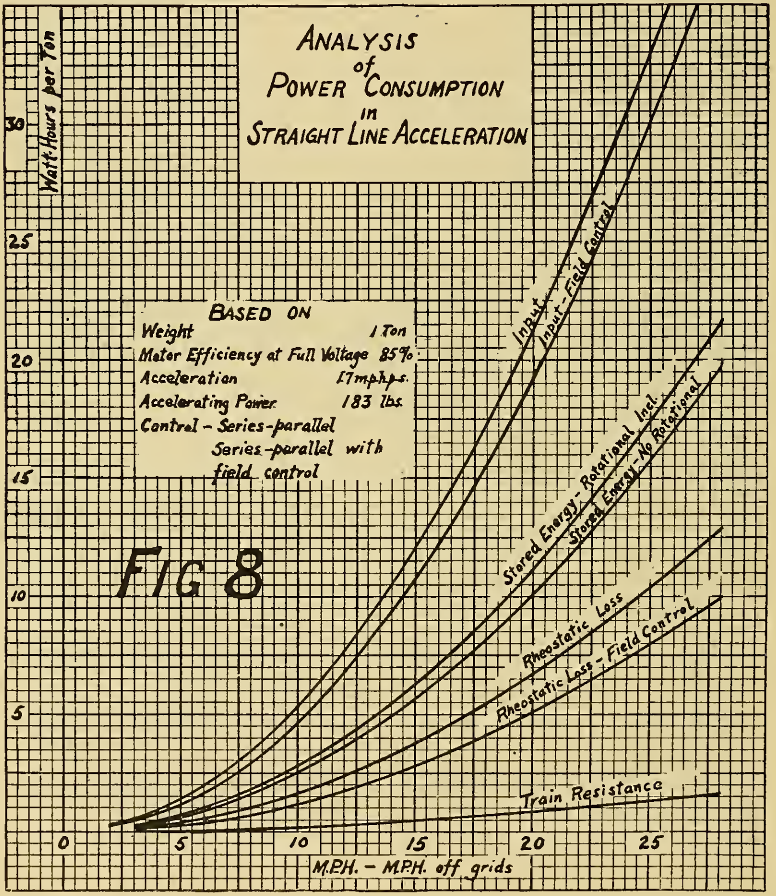


FIG 8

For instance, take the speed time curve in Fig. 6. The energy stored in train at the time brakes are applied is all lost, either in brakes or in overcoming train resistance during braking. The brakes were applied at 16.3 miles per hour. Reference to stored energy curve in Fig. 8 shows that at this speed 7.5 watt-hours per ton are stored. Part of this (4 watt-hours) was stored while accelerating on resistance at an efficiency of 56% (approx.); the remainder (3.5 watt-hours) with motors accelerating on motor curve at an efficiency of about 83%. The first portion, 4 watt-hours at 56% efficiency takes 7.15 from line. The second portion, 3.5 at 83% efficiency takes 4.22 from line, or a total of 11.37 for each stop, or 68.22 watt-hours per ton-mile. The train resistance of 20 pounds per ton would normally require with average efficiency of 80%; 50 watt-hours per ton-mile, but since we have already included the braking period, that distance, or 13.5%, must be deducted, leaving 43.25. The total per ton-mile then is 68.22 + 43.25 = 111.47 as compared to 112.8 given on Fig. 5.

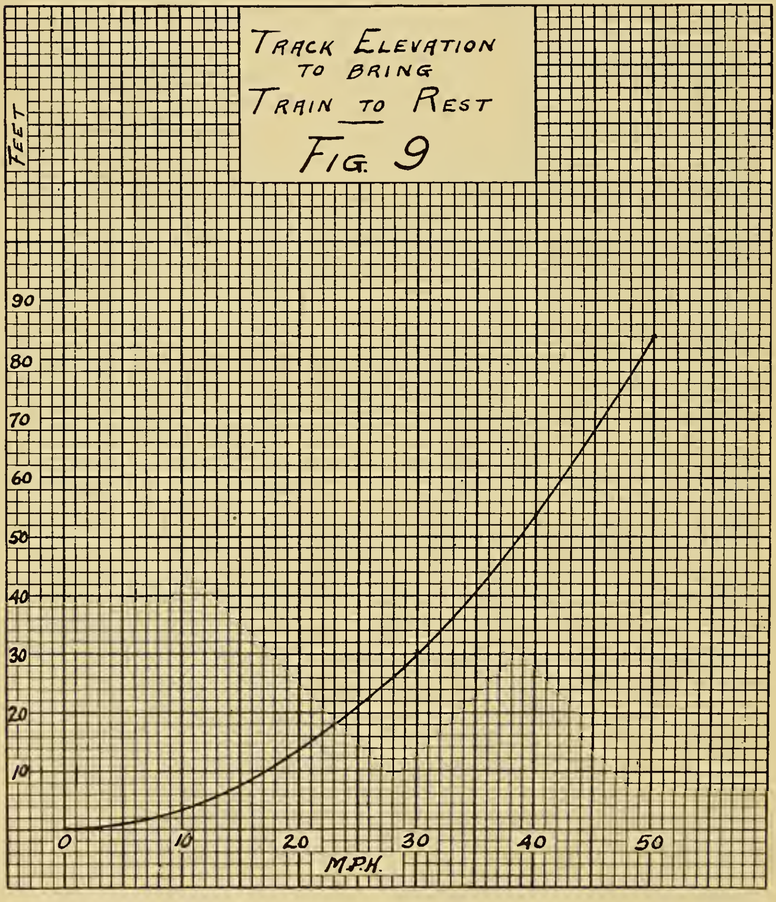
The ratio between the sum of the curves of stored energy and friction to the curve of input is the efficiency of the equipment during acceleration to the motor curve. With the conditions of motor efficiency, train resistance, etc., assumed here, this efficiency is found to be approximately 56%. It will hold approximately constant regardless of the time of acceleration, or whether on level or grade. The rheostatic loss with a given tractive effort is inversely proportional to the rate of acceleration; in other words, if the car were starting on a grade that would cut out the rate of acceleration in half, the time on the rheostat would be doubled and the rheostatic loss double that shown on the curve. This is a very convenient curve to have, since everything is plotted in terms of watt-hours per ton. It is a good check on speed time curves.

There are various other means for saving rheostatic losses, notably one system by which the voltage on the motors is varied by means of a motor generator set, the motor of which takes power from or gives power to the line. Such a system is in operation in Paris and is reported to be giving very economical results. We understand that it is also operated so as to vary the voltage applied to the motor during the braking period and consequently regenerate the stored energy of the train and return it to the line, thus performing a double function. Such a system, however, must require a relatively large capacity of motor generator set on the car, and as it would require a shunt or compound field winding, not only on the M. G. set, but on the main motors in order to return energy to the line, we would expect a very sensitive machine when operating at the usual variable voltages that are found on the third-rail system. Further, the cost of the M. G. set and the extra cost of motors and control would be considerable, and the additional weight to be carried around and the losses in the M. G. set will go a long way toward absorbing any savings that might be made.

LOSSES IN BRAKES AND REGENERATIVE CONTROL.

Regenerative control and regenerative braking are popular names for any system of control that permits the energy that is usually lost in brakes in descending grades or in stopping trains, to be regenerated or converted into electrical energy that may be used by other cars or trains. This portion of the energy used by electric railways is usually a large part of the total and is in most cases entirely wasted. How to prevent this waste of energy, which not infrequently amounts to 40% or 50% of the total used by the car, has been a regular will-o'-the-wisp to a great many engineers. The amount of energy is so large that it is of far greater moment than any other single portion of the total energy used and is worthy of the most serious attention.

One of the schemes for saving this energy is that of elevating the station tracks above those between stations, thus changing the kinetic energy of the moving train to the potential energy of the train on an elevation. This is theoretically the most efficient method that can be devised, but a little consideration of it will show why it has not been more often used. In order to convey to the mind quickly an idea of the requirements for such a system, I have shown in Fig. 9 a curve showing the heights to which station tracks would



have to be elevated in order to change all of the kinetic to potential energy for various speeds. The speed time curve in Fig. 6 shows the brakes applied at a speed of 16.3 miles per hour. Assuming that the rotational energy of the train is sufficient to balance the train resistance, it would be necessary to elevate the track at every stopping place 8.9 feet in order to save the energy that is dissipated in brakes on this typical run. This is, of course, out of the question for a street railway. A train stopping from a speed of 25 miles per hour, which corresponds to elevated railway service, would require station tracks elevated 21 feet in order to store the energy lost in stopping. A train running at a speed of 40 miles per hour would climb to an elevation of over 50 feet before coming to a stop. These figures are sufficient to show the impracticability of this method of saving the kinetic energy in a train for any class of service except subway and elevated railways, where the number and location of stops are quite definite. Even in such service the scheme is open to the following objections which make it impracticable.

1. It would greatly increase the cost of any construction.
2. Elevated railway stations would be so high as to require elevators to take passengers to and from the streets.
3. It is possible only for very short trains. At a rate of braking of 2 miles per hour per sec., which is a fair average for heavy electric trains, a train stopping from a speed of 25 miles per hour moves a distance of approximately 228 feet. A single car, if short, could save most of the stored energy by climbing a grade of 9% for a distance of 200 feet, tapering off to a level of both bottom and top of the grade and giving a total rise of about 20 feet. With two or more cars in a train the average rate of braking would be decreased, due to the fact that only a part of the train is on the grade at one time. To keep up the rate of 2 miles per hour for braking, it would be necessary to dissipate more and more energy in brakes as the length of train increases, and the elevation must be proportionately decreased. Even then it is very difficult to save any considerable portion of the energy, for the entire train should mount the grade during the stopping period, which is manifestly impossible with long trains. About all that can be done with such trains is to mount a long, low grade before braking actually begins and ending so that the entire train can be on level track at the station. This grade would have to be mounted during the coasting period, which would slow down the schedule unless the motors were geared for higher speed.

Without pursuing the matter further it is apparent that practical operating conditions would be very seriously interfered with by such a scheme and that it is adaptable only under certain special conditions of operation.

The use of the electric driving motors as generators returning energy to the line during braking periods was one of the earliest arguments in favor of electric traction. It has been realized only to a very limited extent in actual service. The three-phase railways in Italy and Switzerland were the first to use this plan in extensive commercial service. It is well known that an induction motor driven above synchronous speed will act as a generator and will supply power to the system from which it derives its magnetizing current. A locomotive driven by induction motors will, when connected to the line, therefore maintain a practically constant speed regardless of whether it is going up hill or down. In the former case it takes power from the line; in the latter, feeds power into the line. This system is now used with marked success on the Italian State Railways and is also used on the split-phase locomotives that will shortly be put in service on the Norfolk & Western Railway. The operation of the latter locomotives is exactly the same as that of three-phase locomotives, both in running and in regenerating. The advantage of being able to hold a heavy train without the use of brakes when descending a mountain grade is of far greater importance than the mere saving of power would indicate. The wear and tear on brakes on these heavy grades is enormous and there is a continual danger from accidents, all of which are overcome by the use of regenerative control. The locomotives have been a perfect revelation to the operating men on the Norfolk & Western in this respect.

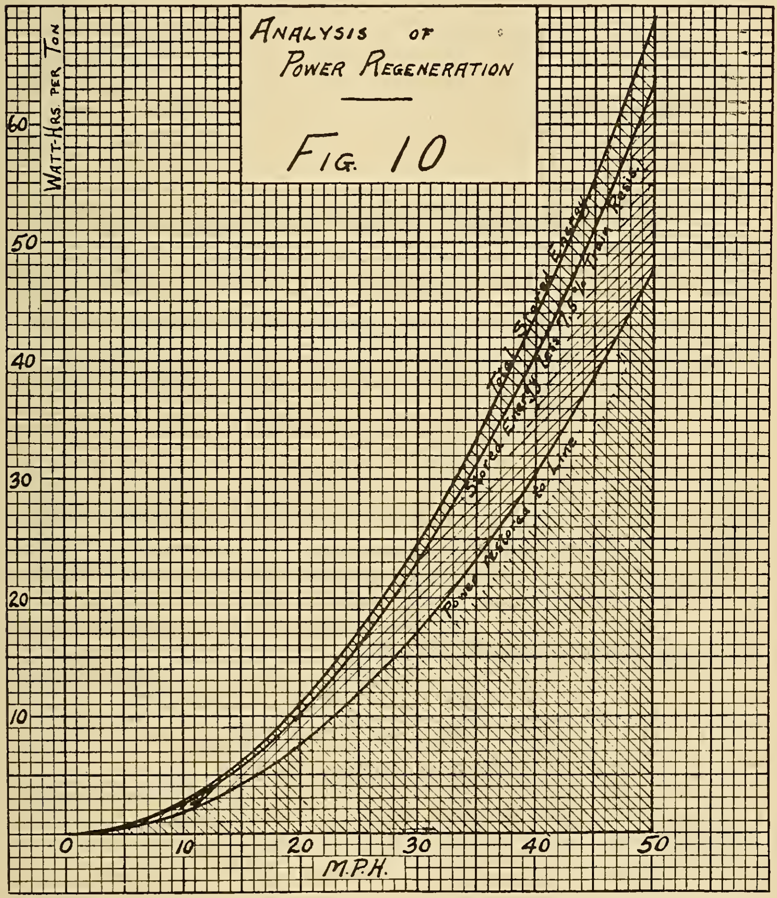
Induction motors can be used to some extent for stopping trains that are running above the minimum synchronous speed, by changing the motors from the high speed to the lower speed combination and gradually reducing the speed by means of the resistance in the secondaries of the motor. They are, however, not particularly efficient for such work on account of the rheostatic loss and the fact that the minimum speed that can be reached in braking is the lowest synchronous speed.

With direct current on the line, regeneration has been accomplished by the use of shunt motors, but these have been used only to a very limited extent and chiefly in Europe. Shunt motors are similar to induction motors in being inherently constant speed machines. The shunt motor, however, has the advantage of a wide range of speeds which are secured by changes in the field strength. For this reason, it is much more efficient for stopping trains than the induction motor. It has the disadvantage of not being suitable for railway operation on account of its liability to flash under sudden changes of voltage which are bound to occur on any railway line. The shunt motor is also necessarily larger and more expensive than the ordinary series motor, is less foolproof and requires a more complicated control system. These reasons appear to have been ample thus far to prevent its extensive use.

Another scheme for regenerative control is the one which has already been mentioned under rheostatic losses, consisting of the motor generator scheme which is in use in Paris. The lack of more published data on this scheme would seem to indicate that it has not been so successful as to be of a revolutionary character.

A great many other schemes have been proposed, most of which have never gone farther than the Patent Office, but it is hoped that some plan will be developed that will prevent this enormous destruction of energy that at present costs a great deal simply to destroy.

Curve No. 82131.



No. 82131

In order to show the possibility of regenerative braking for stopping trains, Fig. 10 is given. This shows the stored energy in terms of watt-hours per ton and speed in miles per hour, the portion of this that would be required for overcoming train resistance assumed to be 15 pounds per ton with a braking rate of 2 miles per hour per sec., and the portion that could be regenerated, assuming that the train could be brought to rest by regeneration with an average efficiency of 75%. This is as much as can reasonably be hoped for in the present stage of the art, but shows plainly the great stake for which to work. The speed-time curve shown in Fig. 6 shows the brakes applied at a speed of 16.3 miles per hour. Even with the high train resistance of 20 pounds per ton and the low braking rate of 1.5 miles per hour per sec. assumed for this typical run, 27.5 watt-hours per ton-mile, or approximately 25% of the total power used by the car could be returned to the line if it were possible to regenerate at 75% efficiency until the car could be brought to a standstill. Even with an efficiency of only 50%, 18 watt-hours per ton-mile, or over 16% of the energy would be saved.

In the opinion of the writer, the essentials of an equipment for regenerative braking with direct current motors are the use of the standard series wound motors and a control equipment that would add but little weight and complication to that used without regeneration, since every bit of additional weight and complication would mean additional first cost, additional cost of maintenance and additional power to carry it around. The point would soon be reached where the extra cost would balance the saving.

CONCLUSION.

The foregoing by no means covers the ground for possible saving in power consumption. Nothing has been said directly concerning the importance of correct gear ratio or the correct operation of equipments so as to take advantage of the benefits of rapid acceleration, long coasting, quick braking and short stops; of the saving in power required for lighting by the use of highly efficient lamps now on the market, and the best distribution of the light, or of the latest methods of heating cars by circulating heated air by means of fans. Neither has anything been said in regard to line loss and its relation to the reduction in peak loads by means of field control and proper gear ratio.

These point have all been discussed as, indeed, have most of the points in the paper many times before. It is confidently believed that without considering the possible saving in power consumed by auxiliaries or in line loss enough has been said to fully substantiate the claim made at the beginning of this paper. The reduction of dead weight per passenger, the adoption of frictionless bearings and the widest use of field control with motors of steep speed characteristics and efficient handling of cars will alone be sufficient to save more than 40% of the power now used on a great many roads. Any saving that can be accomplished by the development of a successful scheme for regenerating the power now lost in brakes would be so much clear gain.

DISCUSSION.

Harry H. Adams, ASSOC.A.I.E.E.: The author of the paper has certainly touched on a question of deepest interest to everyone in railway work—the matter of economy in our equipment. I have been particularly interested in it and have seen a great many steps taken to bring about the results that we are getting today. I remember that in one of the experiments we carried on we had under consideration the question of going into the higher gear ratio by the use of 3½-pitch gearing. We thought we were going to get the real answer there, but found that that gearing was rather noisy and we experienced difficulties which we did not have with 3-pitch gearing. The last equipments that we have been getting, which combine the interpole with the field control, seem to give the economies we have been looking for, and although I do not say that we want to stop there, we have made great advancement in the direction of effecting economy. The equipment itself is very interesting from the standpoint which Mr. Storer has outlined in the economies in the rheostatic losses.

There is another feature about the use of the slow-speed armature and the short field, it gives a very smooth acceleration. We can get a high acceleration and at the same time a smooth one. I like the expression used by the manufacturer's representatives in describing the accelerating, that is, the equipment has lots of "rubber" in it. We experimented by taking the controller handle and slamming it the way round, this resulting in no apparent jerks in the acceleration. It makes an exceedingly practical equipment for service such as we have in Chicago, and the equipment seems to stand most any test to which we put it. We have a few tunnels in this city, and the question that was frequently asked was, "Well, will it go through the tunnels?" We answered, "Yes." We tried it and it went through and operated on the grades just as well as any of the other equipment running there today. We stopped and started on the grades without difficulty.

The economies represented in the development of the electrical equipment for surface work Mr. Storer has pointed out. We get the 33% he mentions. There is no question about that, because many of us have seen the four motor equipment where we average about 4 kw. per car-mile, and with the new two motor equipment this has been reduced to 2½ kw.-hr. per car-mile. Some tests were made with this equipment. We found the watt-hours per ton-mile down as low as 119, showing that we are getting good economy out of the field control. In these tests we carried out some rather interesting work. We had a set of instruments that told us almost everything that we wanted to know. In the first place, we had an instrument that gave us the time we had the current on. Then we had a coasting clock; we rigged up an ingenious scheme to give us the time of braking, and the only time we had to take was the time to stop. The scheme for determining the time for braking was simply a combination of tapping into the brake cylinder and leading an air pipe up to the board holding the instruments, and at this point an electrical switch was actuated by the air pressure, this switch operated an electrical circuit in connection with a current clock which recorded the time of the brake application. We were compelled to allow for the lost motion in the brake application, but this was taken care of by a definite amount of lag in the application of the switch. The motorman was instructed to release his brake just as soon as he had actually made his stop, so as not to get any longer interval on the recording clock than the time for application of the brake. The accelerating speed we obtained with this equipment in our test ran as high as two miles per hour per second.

In connection with the apparatus used for the test, there was one particular piece of apparatus that we used which was exceedingly interesting, although I am not going to describe it. I will ask Mr. Storer to describe this, if he feels like doing it.

H. A. Johnson: After the able paper by Mr. Storer and Mr. Adams' discussion, I feel a little backward about taking up much of your time. Possibly one or two of the problems which have come to our attention may be of interest.

In the first part of his paper Mr. Storer makes a statement which appeared to me at first as a little bit rash, but he made a very good effort at substantiating the statement. The statement to which I refer is that "not less than 40% and possibly 50% of that 1,000,000 tons of coal used for furnishing power could be saved every year." As I listened to the paper I understood that the 40% or 50% comprises all of the various items which Mr. Storer took up, and some which have not been worked out and made a commercial proposition, so that at the present time if we were to scrap or throw away all of our present equipment and put into service equipment which has been sufficiently tested out, any operating company would take chances on operating it, and there would be nothing like a 40% or 50% saving in power.

Reduction of weight is a very interesting subject and a very important one from the standpoint of the equipment and power engineers. Mr. Adams has had a great deal to do with the reduction of weight in surface cars. The statement that it costs 5 cents per pound per year to carry excess weight was made at the convention of the American Electric Railway Association in Denver, 1909. That statement was accepted immediately, without condition, and many of the people who accepted it did not fully realize the circumstances and conditions surrounding it. However, it has spurred all of us to the point of looking to the reduction of weight. As an example of what this has done, I might tell you that in 1904 the Metropolitan Elevated Railway designed and built a steel car which was the first steel car built for subway or elevated traffic. That car is still being run on the West Side line, but only during the rush hours as an emergency equipment. The reason is that the car weighs so much we cannot afford to run it except when absolutely necessary. That car is not insulated in any way, We have now put in service a large number of steel cars, and by careful consideration of the weights and experience gained since the first steel car was built, we have been able to put into service steel cars thoroughly insulated which weigh no more than our wooden equipment. The weight of cars may determine whether a railroad is operating on a paying basis or should be in the hands of a receiver. My attention was called to a railroad on which the operating conditions were such that it was necessary to put on the lightest possible car which would carry people. They had put up to the car builders the proposition of building a car which would not weigh over 12,000 pounds total weight. They figured that by operating such a car they could operate satisfactorily under the conditions. If they had to put in operation a heavy car, there was not traffic enough to pay to run the car. It might be well for some of the interurban roads to look into this phase of the problem. Many roads are running large cars where a smaller car would answer the purpose nine-tenths of the time. The other tenth could be handled by an additional car operating with multiple unit control.

We can also add to the experience of the surface lines relative to interpole field control motors. We first put interpole motors in service in 1908. Our experience was so satisfactory that when the field control feature was brought out we were the first to adopt it for elevated or subway work. We put the first field control motors into service somewhat over a year ago. These equipments have operated entirely satisfactorily up to the present time. Our experience previous to putting the field control motors into the service was that the heavy currents which are handled during acceleration were very exacting on our control equipment. We had some cases where control equipment, carrying heavy current, was giving us considerable trouble, while the same control equipment installed with smaller motors carrying less current gave no trouble whatever. The fact that we could put on a field control motor and reduce the maximum current was a very important feature to us. You will readily realize that with the heavy equipment of the large motors, the current handled is a much more serious problem than on the surface lines. The equipments on the elevated roads, where we have multiple unit operation with automatic acceleration, have become very complicated. In fact, they are getting so complicated we have some difficulty in teaching men to properly inspect and repair the equipment. In the past year, we are glad to say, there has been a tendency to simplify the equipment, and I am also glad to see that the field control feature has been added with practically no complication.

I am much interested in that part of the paper referring to regenerative control, or returning part of the power to the line.

No doubt many of you have noticed the rise in the track at many of the South Side stations. This varies from 3 to 5 feet at all stations between Twelfth street and Indiana avenue. I have often been asked the question if the structure was so built with the idea of saving power when stopping at the stations. We are frank to admit that it was not. That feature came when the third track was put in. There was a condition of clearances which made it necessary to raise the structure at the different stations. However, we are obtaining the benefit of that rise, which is clearly shown on equipment operating on the South Side road in comparison with equipment operating on the other roads. It is my opinion that in working up any system of regenerative control it must be worked up without adding undue complication to the present equipment. If that can be done I am very sure that the railroads will be ready to take it up after it has been thoroughly tested out.

W. Thorn (Asst. Engr. Board of Supervising Engineers): I would like to ask a question in connection with the loss curves. In regard to the motor losses, the curve shows that the minimum point was reached at about 70% of full load. Why is that?

In regard to the saving in energy in watt-hours per ton-mile, brought about by the field-control equipment, some tests have been made from time to time which indicate that the saving runs about as shown in Mr. Storer's curve, namely, about 9%. It may be interesting to compare that with the total cost of operation. Taking this at 26 cents per car-mile, including interest on the investment, and with 3½ cents per car-mile for power, which is roughly correct, for the old equipment, we have about 13% of the total cost of operation for power under old conditions. Under new conditions, assuming the power saving above indicated, the total cost of operation would be reduced about 4%. In other words, it would be equivalent to an increase in net earnings per car-mile of about 25% (under the assumption of gross earnings of 30 cents per car-mile)—a very gratifying result.

E. J. Blair: In looking at the savings from a power point of view, ten per cent, for instance, as applied to the power requirements for the elevated railroads or surface lines, is an enormous saving and we try very hard to get even 2% or 3%. I might say that on both the surface and elevated lines an effort has been made —a very determined effort—to school the motormen themselves in saving power, and recent strenuous attempts on the elevated lines have resulted quite satisfactorily. That is to say, a 4% or 5% saving can be accomplished with an ordinary amount of schooling of the average man with the equipment in hand. Since power is such a large item in railroad work I feel that the power engineer and the equipment engineers will have to dig in very hard and cut these power losses down. Mr. Storer's paper is somewhat of a revelation to me in that line. I would ask him if satisfactory results have been attained with the Johnson-Lundell regenerative control system. I presume that is the system to which he refers as in use in Europe.

President Jackson: I feel that we should be very grateful to Mr. Storer for giving us this paper, because we hear from a man who speaks with knowledge and authority, and we can rest assured that his statements can be relied upon.

In 1909 when the "five-cents per pound saving" might be considered to have become a slogan it was quite proper that it should have become such. At that time our traction people thought that the light car was almost useless for heavy traction service and they were going to atrocious excesses in the matter of heavy cars.

In connection with the regenerative systems used in Europe, my observations lead me to the conclusion that the European operating and maintenance men will operate and take care of equipment which it would be impracticable to introduce in America.

Another point touched upon by Mr. Storer, is the beautiful effect of the braking obtained by the regenerative control. For instance, the cascade motor control on some of the Italian railroads, if such braking is well worked out, is something we hardly know of in America. In those trains, instead of having the slap-bang effect that we have on many of our trains, they have such a perfect braking effect that it is practically impossible for one to tell when the braking actually begins except for a slight throwing back if one happens to be standing in the middle of the car.

J. W. Mabbs, M. W. S. E. I am particularly interested in this paper tonight, not because I am interested in any ordinary traction line, but because I am interested in a traction proposition where the requirements are much more severe than anything which has been presented tonight. The grade percentage is infinity and the stops, instead of being four or five to the mile, run from 100 to 400 per mile. We experimented on field control, and also on returning current to the line. These features have been worked out in this traction line for ten or twelve years, and I might say that we have a kilowatt consumption of 3½ kw. per car-mile. When you take into consideration the *number of stops* and the *grade,* the figures mentioned in the paper are cast somewhat into the shade. I refer to an electric elevator.

Mr. Adams: Mr. Blair's remarks about the saving reached in connection with their motors reminded me of a similar experience in New York City. It was during the wave of "coasting" that went over the country; we decided we would test out the 34th Street line, which is a heavy cross-town line. We had the line metered, and observed it for a week, taking the equipment and passenger load and reducing everything down to watt hours per ton mile. No instructions were given to any of the men during this week, and in fact the men did not know that any observations were being made on the line. Then the next week we instructed those men particularly in the art of coasting. The third week we observed the line again, with the result that we had a clear 10% saving as the result of the instruction. So we can accomplish a great deal along the line of instruction, even without the use of instruments.

T. Milton, M. W. S. E. I would ask if, among the regenerative control schemes, the shunt motor scheme has been tried with any great success in railway work, and whether the author thinks there are any great possibilities with that scheme.

W. E. Symons, M. W. S. E. Although I am not an electrical engineer, there are one or two questions along the line of electric transportation, or the cost to produce transportation, particularly in local service, on which I would be glad to hear the author's views.

The first question is with respect to the length of time, expressed in minutes and seconds, required to stop trains of different weights and at various speeds, the elements entering this calculation to include the following:

(a) Period of time in decelerating the train from running speed to complete stop at station.

(b) Period of time standing at station.

(c) Period of time accelerating train from zero to running speed again.

Total of a, b and c to constitute actual time to make stop.

The second question is with respect to the cost to stop trains of different weights and at different rates of speed. The elements entering into this item would embrace the following:

(d) Wear of brake shoes and car wheels.

(e) Wear and tear of couplers and draft gear.

(f) Electric current expended in making stop.

(g) Electric current expended in accelerating train to normal speed again.

(h) Any expense to electric equipment or cars incident to the stop that would not have been necessary if stop had not been made.

Total of d, e, f, g and h to be considered actual cost to stop trains.

In considering questions similar in character to the foregoing in connection with steam railway operation, these points are being followed very closely by the State Railway Commissions, the courts and all others who have to do with the question of the cost to produce transportation of various kinds, and while the electric railways are not, as a rule, handling a very large volume of through passenger or freight business, they do handle a very large volume of local or suburban passenger business, which is of a character generally similar to the suburban business of the steam railways. Therefore, in my opinion, the foregoing information with respect to the length of time required to stop electric trains and the cost of making these stops would not only be interesting information, but would be quite valuable in considering similar statistics with respect to steam surface railways, and I feel quite confident that the author of the paper of the evening is well able to give us detailed and reliable information on the points mentioned.

CLOSURE

The Author:—In Mr. Adams' remarks, he called attention to a certain instrument that was used in making tests on some of his equipments. This is an instrument which was manufactured by the Westinghouse Company and is designed to measure the root-mean-square currents. As is well known, the copper loss in a series motor varies as the square of the current, so that, in testing an equipment by the old method of taking 5 or 10-second readings, it was necessary to square the readings, take the sum of the squares, and obtain from that the square root of the mean square current, or the R. M. S. current, as it is usually spoken of. This current is the one which determines the average $C^2 R$ loss in the motor. The instrument which Mr. Adams spoke of is a very simple affair, consisting primarily of a thermos bottle containing a small resistance and a certain amount of water. The resistance is put in parallel with a shunt in the motor circuit, and therefore, receives a current that is always proportional to the current passing through the motor. The loss in the resistance will be proportional to the square of the current and is measured by the rise in the temperature of the water in the bottle. Having such an instrument properly calibrated, it can be connected into the motor circuit, and the rise in temperature at the end of any period will enable one to read directly from calibration curve, the root-mean-square current in the motors directing that period. It is an extremely simple instrument, and will probably be on the market before long. It is something which should be in the possession of every electric railway, as it is a very definite and opposite measure of the work that the motors are called upon to perform, and will save an enormous amount of labor.

I knew that the electric railways, both surface and elevated, in Chicago had engineers who were thoroughly up to date, but I did not know that to the Chicago engineers belong the credit for the first steel car. I have known, however, that they are always the first to adopt the up-to-date electrical equipments, as is shown by their adoption of the commutating pole motors and the field control.

Mr. Thorn asked why the minimum point in the percentage of motor losses is located at about 70% of full load. That is largely because 70% of the full load is more nearly the average load applied to the motor and is therefore the proper place for the maximum efficiency.

In the paper which I have presented this evening, I did not discuss the saving in power which can be made by proper training of motormen. I am fully aware of the enormous savings that can be brought about in this manner, but it is a question of operation, and the paper tonight is confined more to equipments. It is an old story that rapid acceleration, long coast and a quick stop gives the most efficient cycle of operation as far as energy is concerned. If the maximum speed could be attained in an instance with the efficiency of acceleration, as is now obtained, the minimum energy consumption would be realized. The nearest that we can come to that ideal cycle is to make the quickest possible acceleration, cut off power at the earliest moment, coast as long as possible, and then make a very quick stop. Accelerations up to a maximum of 2½ miles per hour per second, and braking at like rates, can be secured with perfect comfort to the passengers if the rates of acceleration and braking are approached gradually so that there is no sudden change.

In this connection must be mentioned the coasting time clocks and other instruments which have been introduced as a check on the motormen, to obtain efficient operation. If properly handled, such instruments will undoubtedly save any company a great deal of money, as a saving in power saves also in the wear and tear on the motor equipment.

Considerable savings can be accomplished by simply training the motormen to know that coasting is one of the things that can save a great deal of power, and if I had included all of such items, I would have had to put the total saving up to 70% instead of 50%. In my paper, I have assumed that the cars are now operated with the maximum efficiency.

A question was asked about the results from regeneration in Europe. I am not sure just what system is in use there, but believe the Raworth system is in use to a limited extent on small street car equipments in England. I have very little information as to the results. The scheme in Paris seems to resemble more the Ward-Leonard system than it does Johnson-Lundell.

Before discussing the infinite per cent grade proposition which Mr. Mabbs mentioned, I want to say that the mere fact that he has operated with 2½ kw hours per car mile, is very indefinite information. It is absolutely necessary to have the weight of the car and the number of stops in order to make any sort of comparison with the equipments which we have been discussing.

Mr. Mabbs: It was two tons.

The Author: A 2-ton car operating with 3½ kw hours per car mile is 1.75 kw hours per ton mile, which is about 14 times the amount originally used by the street car, and it would seem that this could be reduced still more, especially as the elevator, which this car is, has counter weights.

I have not much hope for the possibilities of shunt motors for regenerative control in railway service. Shunt motors are not at all satisfactory for operation on any line that is subject to rapid fluctuations in voltage. Fluctuations in voltage produce enormous rushes of current and are very apt to make them flash. There is very little possibility of such motors coming into general use.

Mr. Symons has asked a question which involves a great many variables, and to which, therefore, no complete answer can be given. The time to stop a train varies both inversely as the rate of braking, and directly as the speed from which it is stopped. I am not prepared to give any figures as to the wear on brake shoes, car wheels, couplers and draft gear, in stopping a train, but the amount of energy consumed on account of making an extra stop on a train is comparatively easy to calculate. A simple example will show how the problem may be approached. A train running at 40 miles per hr. has approx. 40 watt hours per ton stored in it. Assuming that this is stored with an efficiency of 75%, which is probably as high as the average, about 53 watt hr. per train would be required to once more bring the speed of the train to 40 miles per hr. A train weighing 500 tons total would therefore require about 26.5 kw-hr. additional energy on account of the stop. At 1.5c per kw-hr. at the car, this would cost about 40c. The additional loss due to wear and tear on the brakes, tires, etc., would have to be added to this figure. A further increase should be made in case the train is required to make up the time lost in stopping, this amount depending, of course, upon the distance in which it is to be made up. The amount of time lost will depend entirely upon the speed and the rates of braking and acceleration. For steam trains, it is probable that a rate of braking of 1.25 miles per hr. per sec. is about the maximum to be assumed for braking and 0.4 is all that could be expected from fairly rapid acceleration. Electric trains will brake at a higher rate and the initial acceleration, at least, is very much higher. It is very difficult to give any general figures which will be even approximately correct.

RETAINING WALLS ON SOFT FOUNDATIONS

WALTER S. LACHER, Assoc. W. S. E.

Presented February 8, 1915, before the Bridge and Structural Section.

In view of the vast amount of material which has been written on the subject of retaining walls, the writer rather hesitates to burden the profession with anything further. His excuse for presenting this paper is that it deals with walls built under unfavorable conditions, where rules of thumb were of no use whatever, and well-known theoretical treatments presented definite limitations. The solutions of the problems also lead to some rather novel designs.

The Chicago, Milwaukee & St. Paul Railway Company is now engaged in elevating its tracks in the city of Milwaukee on what is known as the South Side, between the Kinnickinnic and Menomonee Rivers, a distance of about a mile and a half. When this portion of the railroad was built in 1871, about two-thirds of the stretch now to be elevated was placed upon a pile bridge, because the ground surface at that time was but a little above the level of Lake Michigan, and virtually a marsh. In the years since that time, this trestle has been entirely filled in. This is true also of the surrounding ground, much of which has been improved with buildings of various kinds. Marked settlement of the tracks has, of course, taken place since the fill was made, but additional material has been placed under the tracks from time to time so that the total settlement which has taken place is not apparent. Many of the buildings in the vicinity, however, show evidence of unusual settlement.

Because of the uncertain conditions, foundation investigations were made at various points within the limits of the track elevation work, which included test piles driven to a depth of 80 ft. and test borings carried to a depth of over 100 ft. The results of these investigations may be summed up briefly as follows: Immediately below the surface to a depth of 10 to 15 ft., there is a deposit of filled material varying from gravel and sand under the main tracks to refuse of various kinds under side tracks and unoccupied portions of the right-of-way. Below this to a depth approaching 80 ft. below the ground surface there are numerous, though rather poorly defined strata, of wet, slimy clay and fine sand, the several strata varying in position and thickness at various points along the line. Below this soft material is a bed of coarse sand and gravel of an unknown depth. The pile driving and loading tests proved beyond any question that piles would have to be driven into this gravelly material to be at all reliable. Owing to a lack of a sufficient number of drivers with leads long enough to handle 75 ft. and 80 ft. piles, it was evident that many piles would have to be driven in two sections, connected by a splice; and taking into consideration the results of the

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REINFORCED CONCRETE TRESTLES FOR RAILWAYS.

C. H. Cartlidge, M. W. S. E.

Presented April 13, 1910.

In railroad construction in the West and South it was, and is still quite generally the practice to bridge unimportant streams, ravines carrying little or no drainage, bayous, and marshes, with pile or timber trestles. As the cost of timber increases and as the standards of railroad maintenance are raised, it is the practice on most roads to replace these structures, when they become ripe for replacement, with structures of a more permanent character. Where the drainage areas are small, pipes or masonry culverts are often built and the remaining portions of the bridges replaced by an embankment, and at such a low cost as to be economical. But there are, on most roads traversing the Mississippi valley, a great many pile trestles in river bottoms, and over bayous or swamps, which may not be filled and which, if replaced with steel bridges on permanent supports, would be extremely expensive, because of their great length.

These conditions are very familiar to all maintenance engineers on roads traversing this part of the country, and the necessity for retaining the entire existing opening is, in many cases, perfectly obvious. In most of these cases there is no need for spans of any great length, there being neither ice nor drift to catch upon supports placed closely together. For bridges having the characteristics described, many of them of lengths from one hundred to a thousand feet or more, the writer has devised a construction which seems well fitted to replace the timber or wooden pile trestle bridge. As the wooden pile bridge is the cheapest wooden construction possible, it occurred to the writer, when considering how best such structures might be made permanent, to design a reinforced concrete construction, following the main features of the timber trestle.

An investigation of the reasons for the great economy of such a construction as the pile trestle shows that it is largely due to the small amount of work necessary to be done in the field. There are no cofferdams, foundation pits, or falseworks to be built. Very little raw material has to be unloaded and cared for. The members comprising both the substructure and super-

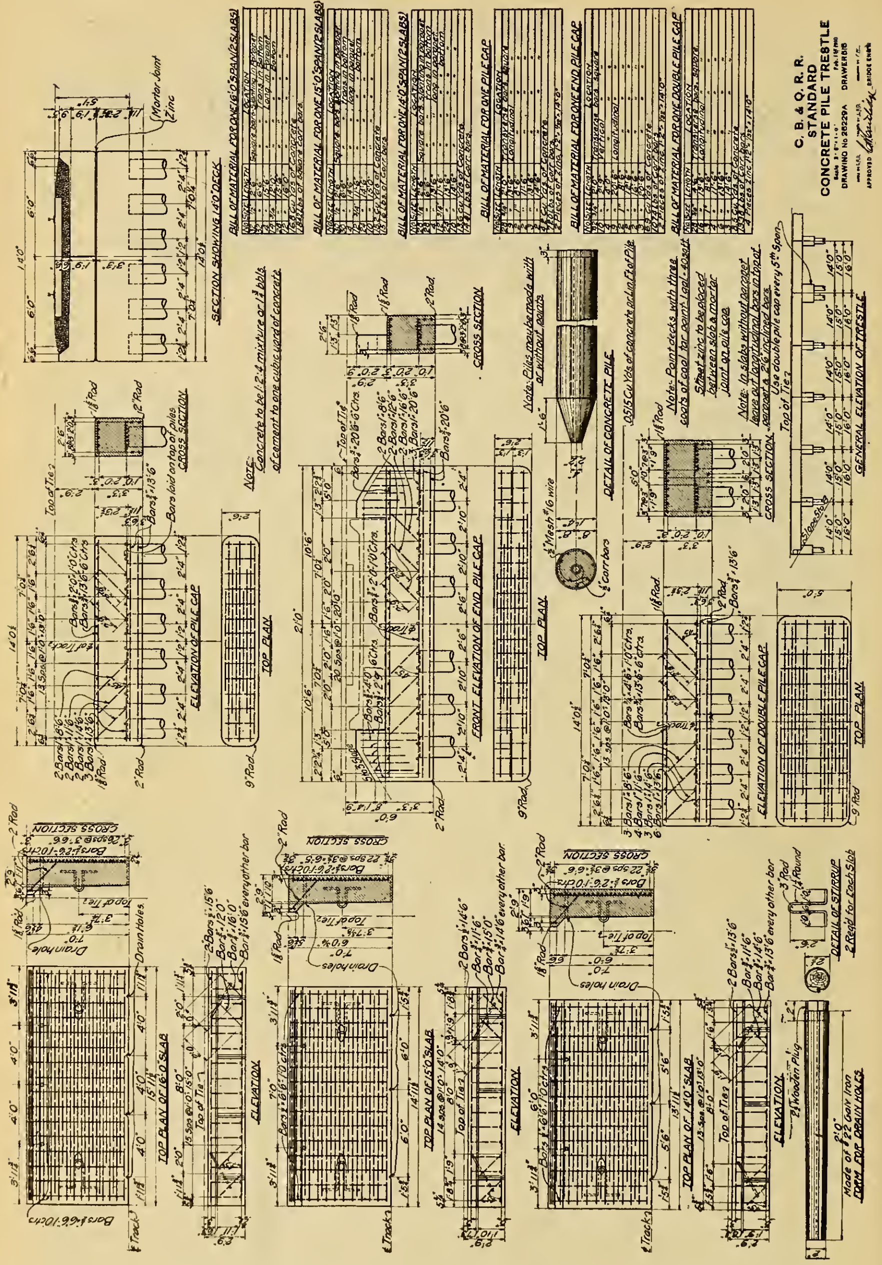
SECTION SHOWING 14'0" DECK
Mortar Joint
Zinc
BILL OF MATERIAL FOR ONE 16'0" SPAN (2 SLABS)
BILL OF MATERIAL FOR ONE 15'0" SPAN (2 SLABS)
BILL OF MATERIAL FOR ONE 14'0" SPAN (2 SLABS)
BILL OF MATERIAL FOR ONE PILE CAP
BILL OF MATERIAL FOR ONE END PILE CAP
BILL OF MATERIAL FOR ONE DOUBLE PILE CAP
C. B. & Q. R. R.
STANDARD
CONCRETE PILE TRESTLE
Note: Concrete to be 1:2:4 mixture or 1¾ bbls. of cement to one cubic yard of concrete
ELEVATION OF PILE CAP
CROSS SECTION
TOP PLAN
FRONT ELEVATION OF END PILE CAP
Note: Piles may be made with or without points
DETAIL OF CONCRETE PILE
Note: Paint decks with three coats of coal tar paint 1 gal.-40 sq. ft.
Sheet zinc to be placed between slab & mortar joint on pile cap
Note: In slabs without parapet leave out longitudinal bars in top of parapet & 2¼ inclined bars. Use double pile cap every 5th span.
ELEVATION OF DOUBLE PILE CAP
GENERAL ELEVATION OF TRESTLE
TOP PLAN OF 16'0" SLAB
ELEVATION
TOP PLAN OF 15'0" SLAB
TOP PLAN OF 14'0" SLAB
DETAIL OF STIRRUP
FORM FOR DRAIN HOLES

Fig. 1. Standard Plan, Concrete Trestles.

structure are taken out and put in place, often largely by machinery and with a minimum of disturbance of the track and delay to traffic. It was evident that if a construction of permanent materials, having the characteristics mentioned, could be devised, the result would be what was wanted.

A structure embodying these features was built and tested, and with the experience gained, a standard plan was drawn up, which is shown in Fig. 1.

It should be emphasized that this construction is suited only for shallow openings, and it is the writer's practice to limit the height of concrete pile trestles to sixteen feet from ground line to base of rail. For greater heights it is his practice to substitute thin piers for the pile bents, although at considerably increased cost.

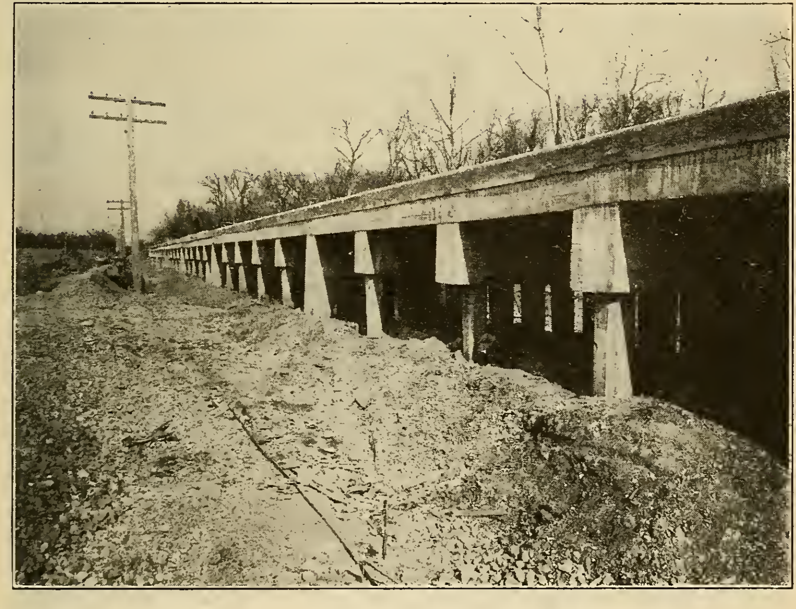

Fig. 2. First Concrete Trestle.

In Fig. 2 is shown a view of the first trestle built, and experience in its construction led to the design of Fig. 3 which is in accordance with the standard plan of Fig. 1.

The construction of these bridges in any great length requires some little organization, and the more thorough this is the less will be the unit cost and the better the construction.

In the bridges so far built, concrete piles of two kinds have been used—one being moulded in horizontal forms and the other made by *rolling* in a machine, under the Chenoweth patents. The moulded piles were used in the first of these bridges. They were sixteen inches square at the butt, had a four-inch chamber at each corner, a taper of four inches in thirty feet on each face, and were pointed at the tip. The reinforcement consisted of four ¾-in. sq. corrugated bars, hooped with No. 12 gauge steel wire, wound at close pitch near the butt and point, and at three-inch pitch over the greater part of the length of the pile. The reinforcement was assembled on a mandrel and the spiral hooping wound around it by turning the mandrel. After the hooping was in place it was tied at frequent intervals with No. 16 soft wire, and the complete reinforcement was then withdrawn from the mandrel.

The forms were of wood, unlined and made so that the sides could be removed as soon as the concrete was firm; the pile was left on the bottom boards until hard enough to stand handling. The reinforcement was hung in the forms by wires depending from the cross braces and concrete, composed of one part of cement to four and one-half parts of gravel, mixed to a slushy consistency, poured in. The gravel was generally screened so that all the sand and pebbles one half inch in diameter or less were retained and used, the coarser aggregate being rejected. The piles were allowed to harden at least thirty days before being shipped. This seems to be about the least time which can be allowed, as attempts to ship and drive piles of less age have not been successful. More extended seasoning is often easily obtained and is to be preferred.

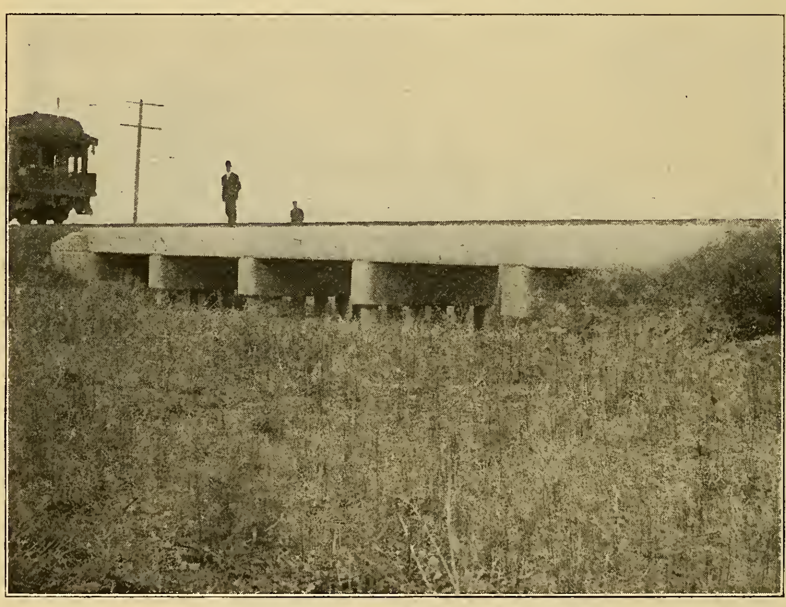

Fig. 3. Second Concrete Trestle.

The *rolled* piles are made in the machine shown in Fig. 4.

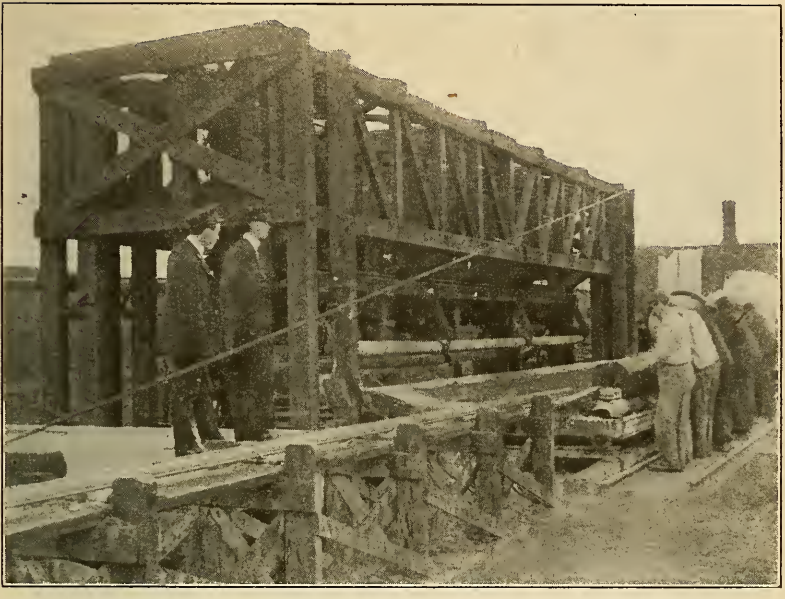

Fig. 4. Manufacture of Rolled Concrete Pile.

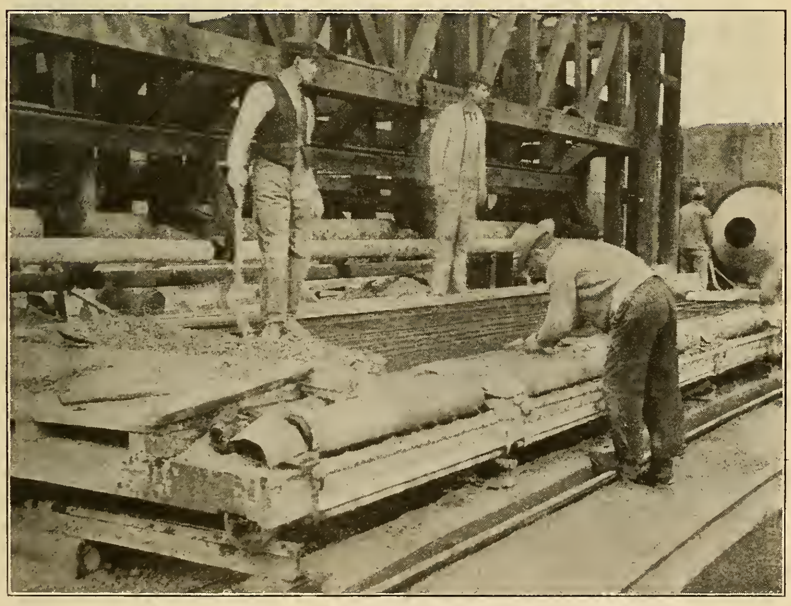

Fig. 5. Rolled Concrete Pile Being Made.

This machine consists essentially of a movable platform, a shaft or mandrel, and means for moving and turning the piles, together with rolls for holding them in line during fabrication. The illustrations, Figs. 4, 5 and 6, show the process quite plainly. Fig. 7 shows the whole plant with some completed piles in the seasoning yard, where the piles are sprinkled frequently to assist the hardening of the concrete.

A somewhat incomplete comparison of the first year's costs of rolled and moulded piling indicates that there is little difference in the cost of the two kinds. As the cost of making reinforcement for the moulded piling was one of the principal items, it was decided to experiment with moulded piling made without taper, the idea being to use a wire fabric, as reinforcement, which could be simply folded into a square and wired together at the lap, thus avoiding considerable labor. The cost of forms is also much reduced if they are not tapered. An efficient plant was designed and is shown in Fig. 8. On each side of each form a rail is placed. A pair of trucks has a short piece of track spiked to it at right angles to the track on which it runs, the level of the latter being such that a car can run off the upper track directly on to the rails between the forms. The car on the trucks is a hopper-bottom dump car and carries a half yard of concrete, Fig. 9. In operation the mixer is placed high enough to dump into this hopper car standing on the trucks. This two-storied car is pushed over to the form and the dump car run off and

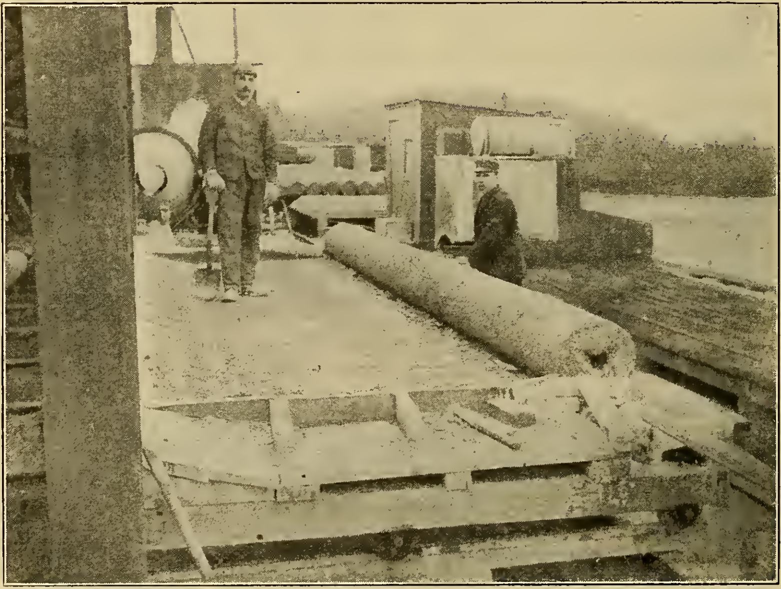

Fig. 6. Rolled Concrete Pile, Nearly Completed.

dumped directly into the form. In spite of the economy of this arrangement no great difference in the cost has resulted, partly because of the difficulty of handling the square piles. On the whole, in the absence of definite comparative tests, the writer is inclined to favor the rolled pile. Tests to determine the rela-

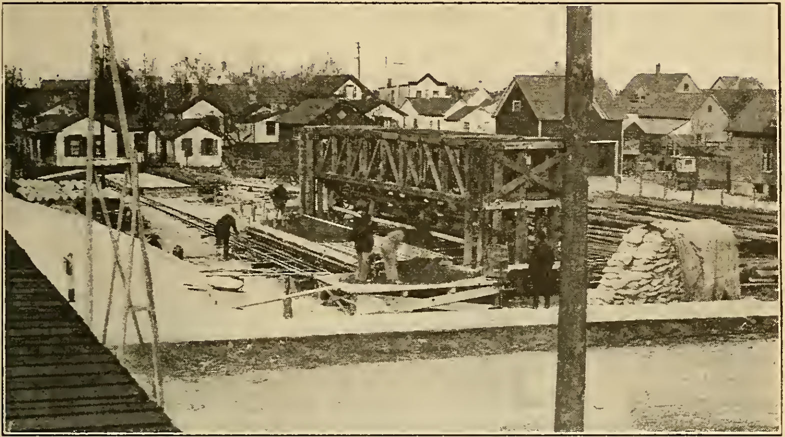

Fig. 7. General View of Plant for Concrete Piles.

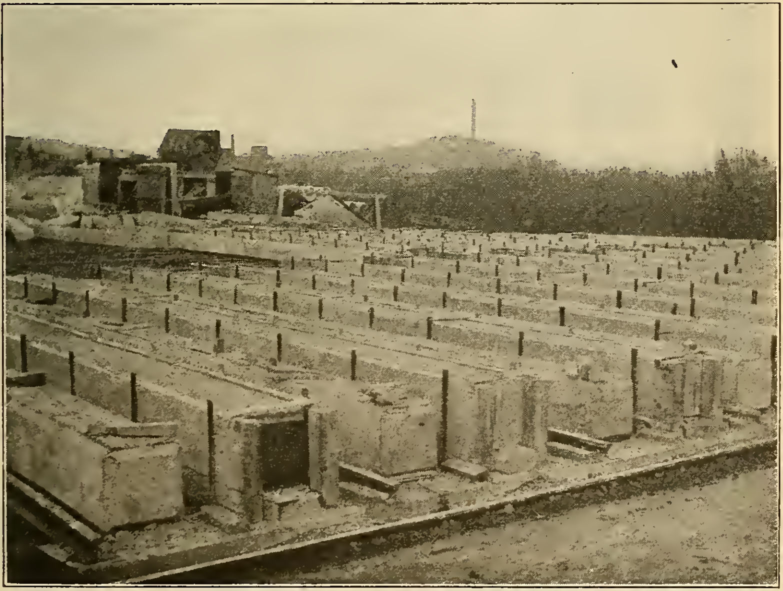

Fig. 8. Square Moulded Concrete Piles.

tive strength of the two kinds will be made, however, for both compression and bending. It is probable that each form of pile will be found to have its own place and use.

As yet, no soil has been encountered in which wooden piles could be driven and in which it has not been possible to drive the concrete piles. In some soils it is expedient to employ a jet; in others, an ordinary drop hammer, a steam hammer, or a combination of the jet with one or the other forms of hammer. It is necessary to lift the drop hammer somewhat more slowly for the concrete pile than for the wooden pile, in order not to set the driver into vibration. A cushion of some elastic material must be placed between the hammer and the pile, and with this precaution very little damage to the head of the pile results, even after long continued driving. As a matter of fact, it is surprising how much punishment a well seasoned pile will stand. When it is necessary to drive the pile below the leads, as is generally the case, the follower is placed on top of the cushion. As the loads on these piles are great it is necessary to drive them to refusal, so that accurate knowledge of the required length is necessary. In case it is found that the piles so driven do not reach the elevation called for on the plans, the depth of the cap is increased accordingly. If it is found impossible or impractical to drive the piles to the depth anticipated, they can be cut off without

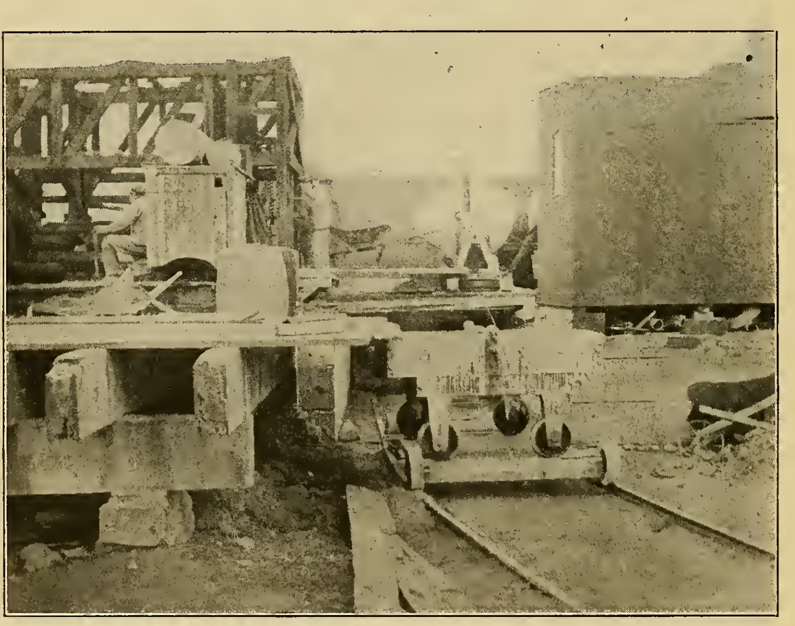

Fig. 9. Hopper Car for Moulded Piles.

difficulty. The cut need not be a smooth one, as the casting of the cap will take care of all irregularities of the head of the pile. Should settlement occur in a finished bent, the strength of the cap is important, so that the loads may be equalized and even settlement result. Experience has shown that the design of Fig. 1 provides sufficient strength. Slight settlement has taken place in two bridges but without causing cracks or damage. As the settlement was doubtless due to the fact that the piles had not been driven to refusal, a mass of concrete was placed about each settled bent, extending from just below the ground line to about three feet below; the slabs were jacked up to grade and a layer of concrete was placed between them and the caps. This is shown in Fig. 10.

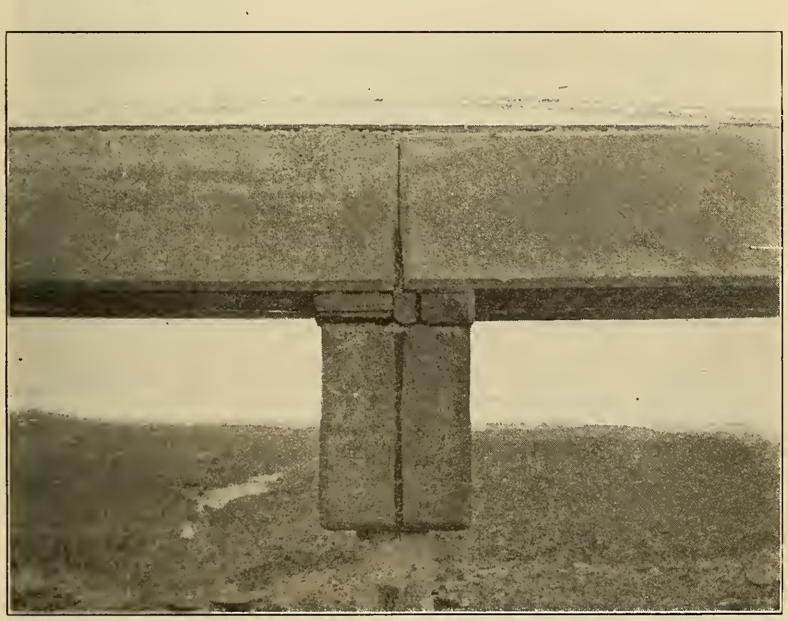

Fig. 10. Concrete Girder, Leveled Up After Settlement.

The manufacture of the floor slabs is best accomplished in a convenient yard, where advantage can be taken of economical methods. Such a plant is shown in the illustrations, Figs. 11 and 12, and in Fig. 13 are shown some of the slabs. It is necessary to provide a firm, unyielding bed. The sides and ends of the forms are removable, and as one span consists of two slabs, a temporary partition is placed in each form to be removed after a half span has been completed. A layer of paper is placed against the slab and the remaining half is cast. Drainage holes are also cast along the dividing line.

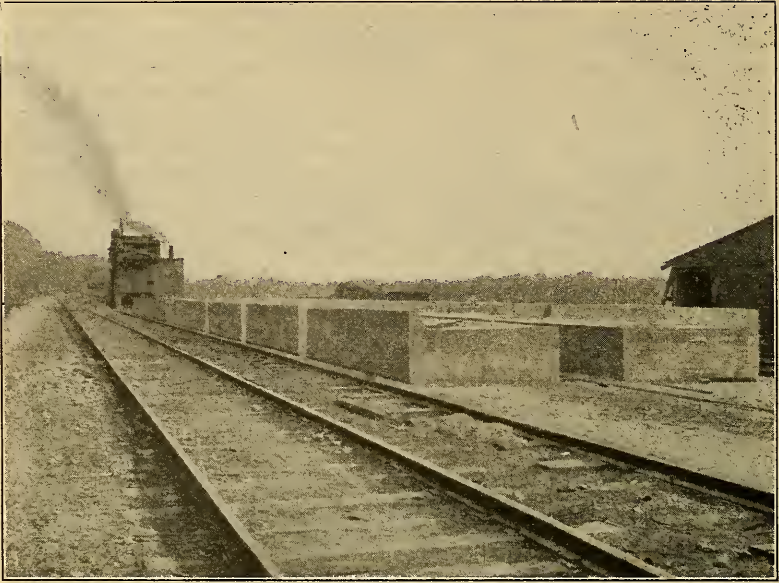

Fig. 11. Floor Slabs in Yard.

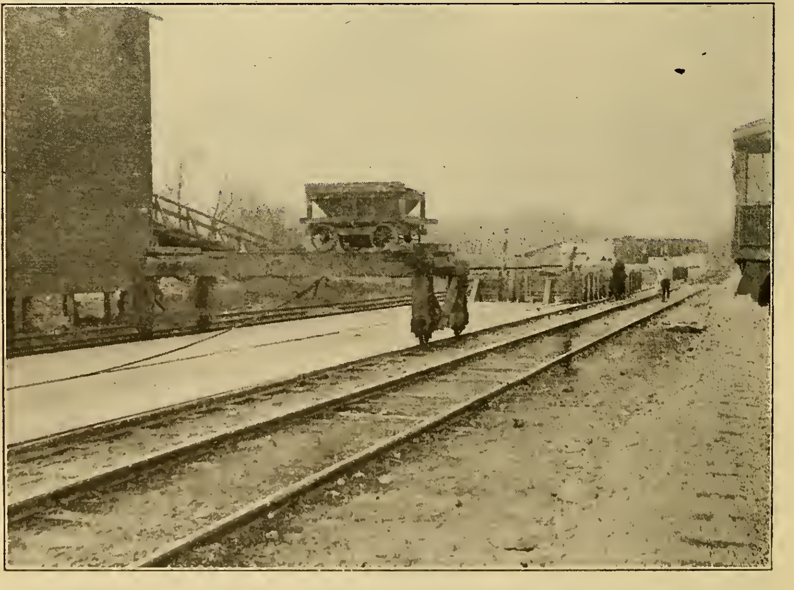

Fig. 12. Plant for Floor Slabs.

By referring again to Fig 1 it will be seen that U bolts or stirrups are set in the upper part of the slab to permit of its being easily handled. These are set at an angle so that there may be a direct pull when attached to a chain, thus obviating the necessity for a toggle-beam when lifting and placing the slabs.

After the slabs have remained in the forms for from two to four weeks, they are lifted by means of a locomotive crane and piled to one side until hard enough for service, the minimum time for seasoning being three months. When seasoned they are readily erected by the same locomotive crane, a mortar joint being placed between the bottom of the slab and the cap.

After being erected the slabs are painted on top with a waterproofing compound, and the joints over the caps are filled with a mastic of tar or asphalt and sand. It is better to fill these joints with such material than to allow them to fill wih sand, as the former will admit of the slight expansion necessary. Thus far, the best material for waterproofing, with which experiments have been made on work under the direction of the writer, has been found to be a paint made of coal tar, Portland cement and kerosene, after a formula published in an engineering periodical a few years ago. This compound not only covers the surface but sinks into and bonds with it, so that two or three coats are sometimes required. It is put on with paint brushes, in the same

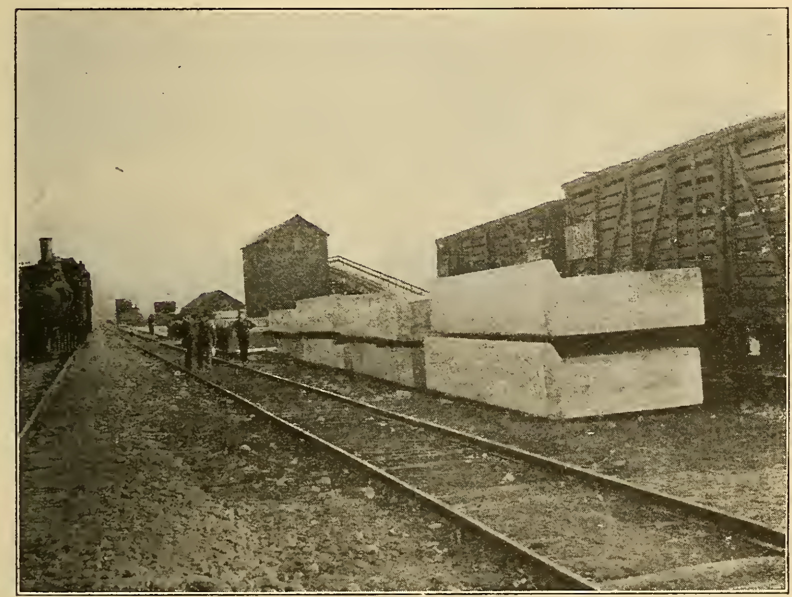

Fig. 13. Concrete Slabs Being Seasoned.

way as ordinary paint is applied. Another valuable attribute is its ability to adhere to moist or even wet concrete. Still another, and not its least recommendation, is its very low cost.

It is evident that in a pile trestle the piling must be capable of transmitting the lateral and longitudinal stresses to the ground, so that considerable bending strength is required.

The double bents are designed to take up such longitudinal stresses as might be apt to place undue bending on the piling. As a matter of fact the stiffness and weight of the floor are such that it is somewhat questionable whether the double bents are necessary. It seems well to put them in, however, as an extra precaution.

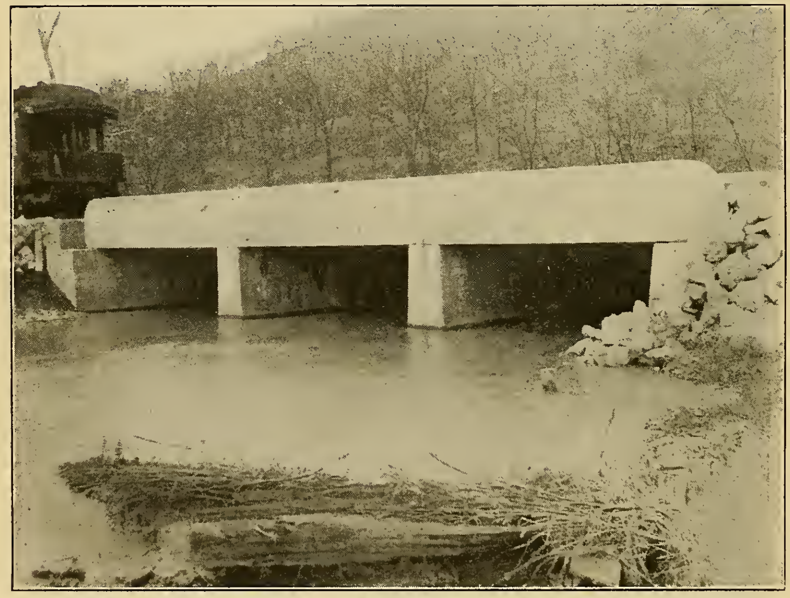

Fig. 14. Through Girder, Concrete Trestle on Piers.

As to cost, it is difficult to generalize, as conditions of traffic, length of structure, etc., have a very important bearing. With men experienced in this work, several bridges of lengths of from 80 to 250 feet have been built at a total cost of from $20 to $26 per lineal foot, and on lines carrying heavy traffic, while in one or two short bridges of two or three spans, the cost has been as high as $45 per foot. For the purpose of estimating, a cost of $30 per lineal foot plus a constant of $300 will be ample for the design shown.

For bridges having a height above the ground line greater than 16 feet, a plan involving the use of thin piers is preferable.

Photographs of several such structures are shown in Figs. 14 and 15. The piers are heavily reinforced and are generally founded upon wooden piles cut off five or six feet below the ground line. Because of the greater cost of these piers, it is generally economical to make the spans longer than 16 feet, spans of 18 to 25 feet being common. A great number of such bridges have been built and have so far developed no defects. When the spans are as long as 25 feet, however, it is impracticable to build the slabs in a plant away from the bridge, because of their great weight. In general, it has been found best to build them on false work adjoining their final position and to jack them into position.

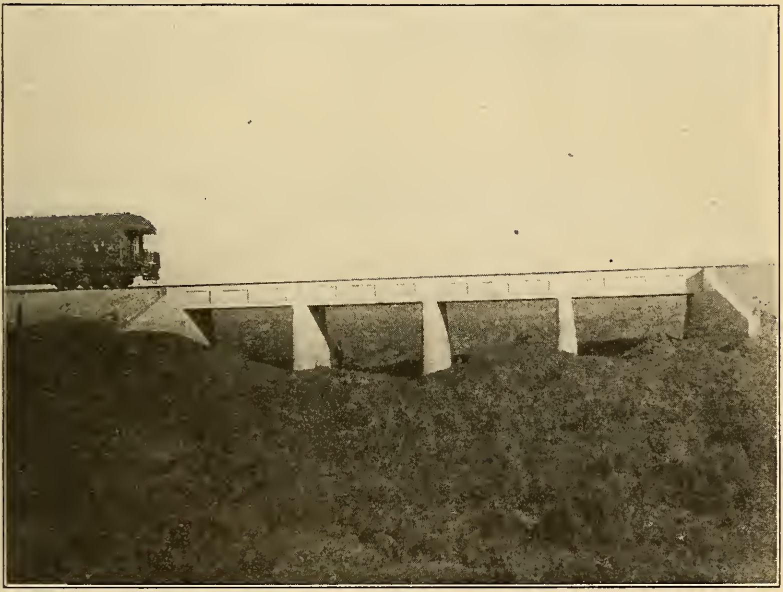

Fig. 15. Concrete Trestle on Piers Over 16 Feet High.

The writer wishes to lay especial stress upon the necessity for the use of the best materials and the most skillful labor on such work. Not only should the cement be tested but also the sand to be used, unless its properties have already been thoroughly established. If the work of making piling or slabs is to be done by contract it should be done by experienced men, under proper specifications and under rigid inspection during every step of the process. If the work is done by company forces, the foreman must be one worthy of confidence, willing to obey instructions to the letter, and intelligent enough to realize the necessity for refinement of the work. The comparative novelty of reinforced concrete, and especially of such designs, makes necessary a most efficient organization for the work, and the placing of all possible safeguards to insure its integrity. Such organization and safeguards have been in effect in the case of steel construction for so long that they have become matters of course, and when reinforced concrete is carried on with similar care and scrupulous watchfulness, no fear need be felt as to its value as a material of construction. Without these, it is needless to say, it is dangerous.

It is possible, under some specifications, to design short span steel bridges on concrete supports which will be as cheap as the designs described herein, but not, the writer believes, of equal strength to the bridges shown in these designs. Further, if the obvious advantages of ballasted, non-corrodible, fireproof bridges are considered, it will be seen that there is a preponderance of good qualities on the side of the reinforced concrete construction.

DISCUSSION.

Prof. Arthur N. Talbot, M. W. S. E. (by letter): This novel type of pile-trestle in reinforced concrete designed by Mr. Cartlidge has now been in use on the C., B. & Q. R. R. long enough to warrant the view that it is a durable and satisfactory form of construction, and that it may well be used to replace wooden trestles of low and medium height where the features of short span and adaptation to ground-slope are advantageous, and where conditions will otherwise warrant the expenditure. The erection features are simple and flexible, and the methods of construction permit the structural pieces to be made under the most favorable conditions and to be thoroughly seasoned before being put into service.

The use of concrete piles for this purpose at first seemed to the writer to be somewhat of an experiment. Concrete piles in foundations are usually placed in large groups and are so tied together by the structure itself that the individual responsibility of a single pile is much less than in a trestle. Concrete columns, as frequently constructed, are subject to the criticism of possible variation in quality of concrete in different parts, giving opportunity for local weakness. The objection to poor spots is especially apparent in a column which is to be driven as a pile. It might seem, then, that the concrete pile would be an element of weakness in a structure of this kind. To the writer the existence of weak spots in piles made by the rolling process seemed extremely probable; and as there are others who may still hold this view, he presents the following tests of rolled concrete piles as having a bearing upon the strength and uniformity of this form of fabrication.

The rolled concrete piles were furnished for these tests by the American Concrete Co. They were made at Racine, Wisconsin, December 1, 1908, at the plant which fabricated the piles used in a bridge foundation. The concrete was reported to be one part Universal Portland cement, two parts torpedo sand, and four parts broken stone, size 1-in. and less. The length ranged from 16 to 24 ft. The section was somewhat elliptical but the average diameter was about 14½ in. The longitudinal reinforcement consisted of five or six ½-in. square, twisted, steel bars which were spaced fairly uniformly and just within the light wire netting which surrounded the pile. There were several turns of No. 14 wire at intervals of about 16 in. which were for use in holding the concrete and netting in place after fabrication. It is seen that the steel reinforcement is light and will not give much additional strength. The piles were shipped to the laboratory when about two weeks old.

The piles were fairly straight. Both ends had been constructed square, instead of having a point at one end. As is usual with this fabrication, the irregular space at the end of the pile formed in the rolling process had been filled in with concrete at the time of fabrication.

The tests were made in the 600,000-lb. vertical-screw testing-machine of the University of Illinois. A few hours before loading, the pile was set in place in the testing-machine and the ends were bedded in plaster of paris. The lower end rested on the bed of the testing-machine. The load was transmitted to the top of the pile through a hemispherical bearing-block. The results are given in the table. As might have been expected, failure came generally at the ends where the finishing of the pile by filling concrete into the irregular space between the folds of the wire netting leaves unfavorable conditions for strength. It is evident, then, that the failures at the end are not representative of the full strength of the pile. In the three cases where the failed end was cut off, the second tests (7A, 9A, and 10A) gave materially higher results, and where the second end was cut off (7B) the test showed a still higher value and the pile broke near an end. The pile which broke away from the end (10A, 3 ft. from the top) gave a strength of 2570 lb. per sq. in. One pile, No. 6 (not given in the table), had been broken in three places in handling, but it carried a load of 156,000 lb., and failed by shattering at the bottom of the concrete.

It will be seen that the piles in which the original end had been removed carried high loads, and that there was no indication of lack of uniformity of concrete throughout the length of the piece. In fact, the appearance of the concrete and the action of the piles during test were those of dense and uniform concrete. It would seem that the method of fabricating these under pressure gives a uniformity which is to be desired. So far as the possible weakness of the ends is concerned, it must be borne in mind that the lower point is in the ground and that with the type of construction described by Mr. Cartlidge the upper end may be cut off, or at any rate is embedded in the concrete cap where it will be protected from lateral failure.

COMPRESSION TESTS OF ROLLED CONCRETE PILES.

Spec.	Length. ft., in.	Equivalent Diameter, in.	Area, sq. in.	Maximum Applied Load, lb.	Average Unit Stress, lb. per sq. in.	Age at Test, Months.	Remarks.
1	24 4	14.4	163	280,000	1720	4	Failed along a diagonal plane about 8 ft. from top. Many wires broken and long. rods buckled at and near point of failure.
10	24 3	14.1	156	264,000	1690	4½	Failed by shattering at top and bottom.
10A	19 9	14.1	156	401,000	2570	12	This is No. 10 with injured ends cut off. Failed along a diagonal plane about 3 ft. from top.
9	20 7	15.0	177	231,000	1300	4	Shattered at top.
9A	19 3	15.0	177	350,000	1980	12	This is No. 9 with injured top cut off. Failed by shattering at bottom (original end).
2	20 5	15.3	184	260,000	1410	4	Failed at top by bulging and splitting; wires broken at end.
7	20 3	14.4	163	271,000	1660	4	Failed by shattering and splitting at top.
7A	17 0	14.4	163	319,000	1960	4	This is No. 7 with about 3 ft. cut from top. Failed by shattering at bottom.
7B	14 0	14.4	163	356,000	2180	4½	This is No. 7A with about 3 ft. cut from bottom. Failed by splitting near top.
4	20 0	15.0	177	214,000	1210	4½	Failed by shattering and splitting at bottom.
5	16 6	15.0	177	257,000	1450	4	Failed by bulging and splitting at bottom; long. cracks extending 18 in. high.
8	16 6	14.8	172	176,000	1020	4	Shattered at bottom.
3	16 0	14.1	156	279,000	1790	4½	Top shattered.

Mr. C. R. Dart, M. W. S. E. (by letter) : Relative to concrete piles, the Sanitary District of Chicago, in the spring of 1909, drove 80 Chenoweth piles in abutments of a bridge for the C., M. & St. P. Ry. Co. over the North Shore Channel in Evanston. These piles were 16 in. in diameter and 35 ft. long, reinforced with seven ⅝-in. round corrugated bars. They were made at St. Louis, Mo., and shipped to Chicago from three to five weeks after manufacture. None were injured in loading, during transportation, or in unloading.

These piles were made of extra large diameter, and with more than the usual reinforcement, to resist possible movement of the abutments. Their large size made the driving very slow, requiring from 600 to 1800 blows per pile from a No. 2 Vulcan steam hammer, with cushion cap, to give a penetration to within about a foot of their tops. The penetration of the pile per blow was imperceptible during the last three or four feet of the driving. The material was clay without boulders.

The piles were driven from 46 to 60 days after manufacture, and notwithstanding the large number of blows received by many of them, not one was injured in any way during the driving. Wooden piles driven at a lower level in adjacent piers were occasionally split under a less number of blows, but of course the driving was done without the use of a cushion cap.

Mr. E. N. Layfield, M. W. S. E.: The author says that the 25 ft. spans were too heavy to be put in place by derrick-cars. Was not that the method that was used on the track-elevation work of Chicago for practically the same slabs?

Mr. Cartlidge: Yes, but the track-elevation slabs were much lighter and only 7 ft. wide, while the concrete-trestle slabs were 15 ft. wide.

Mr. Layfield: Your slabs, then, were for the full width for one track?

Mr. Cartlidge: Yes. We have only one derrick-car, with a 40 ft. boom, on the system.

Mr. T. L. Condron, M. W. S. E.: In the test-report of Professor Talbot I notice that none of the tests showed a load on the pile in the testing-machine of less than 88 tons, and some of them ran above 125 tons. We are more accustomed to think of loads on the piles in tons than otherwise; therefore it occurred to me that it would be of interest to know what the load is which the piles of these trestles have to carry under maximum traffic conditions.

Mr. Cartlidge: Under full ideal load for which the piles are designed, the load is from 20 to 23 tons apiece, the longer spans giving the heavier load.

Mr. Condron: The concrete piles are loaded about the same as ordinary wooden piles, and are thoroughly supported laterally by the surrounding earth most of their length. The test piles that failed at their ends, where in actual construction they would be further restrained, carried from four to six times the load which they are called upon to support in actual service.

The criticism of concrete columns as ordinarily made for building-work would not apply to piles cast on the site in forms, nor to these *rolled* piles. All who have had occasion to examine building-columns know that the greatest trouble comes in the proper filling of a long slender shaft from the top. I have recently had occasion to examine some columns which were cast during the winter, and while considerable care was supposed to have been taken in the casting of these columns, it was found when the forms were removed, that evidently quite a section of ice had formed at the lower ends of the columns, which of course melted later, leaving two or three inches of air-space at the base. It was also found that some of these same columns were frozen, and split from top to bottom as a result. These are conditions that would not occur in the making of a pile, so that it would hardly seem as if these molded piles would have a greater assurance of strength than is found in building-columns, especially columns cast in the winter time. I have been much interested in the description of this rolled pile, which is unique and seems to have a promising future.

Mr. Oscar E. Strehlow, M. W. S. E.: The settlement of the bent referred to by Mr. Cartlidge shows to what extent the slab can be shifted about and still remain intact. I recall two instances of even greater settlement. One was a continuous slab built in place across the head race of the Oliver hydro-electric water power, at South Bend, Indiana, 125 ft. long, with bents about 12 ft. from center to center. A washout undermined several of these piers and the bridge settled about 14 in. The slab which settled with the piers was raised with jacks to a proper grade, and there was no indication that there had been any settlement and there was no crack in the slab.

The other case was an arch bridge, with about 70 ft. spans, at Jacksonville, Florida, where the piers were 8 ft. thick at the top. There was a settlement of about a foot in one of the piers, and holes were drilled in the sides and ends of it; plugs and feathers were driven in, and the pier cracked in two; then jacks were installed and the adjacent arches raised to proper grade. This was about four years ago and the jacks are still in place. After every freshet, as the pier settles still more, the jacks are operated and thus the bridge is kept level. The total settlement now is over two feet but it is gradually decreasing; after it ceases, concrete will be placed in the space in the piers, and the bridge will then be safe and complete.

Mr. Cartlidge: Since writing this paper, the fact has occurred to me—which it is well to lay stress on—that while this construction has its advantages as a method of construction, it is not a cure-all for the wooden-pile trestle, because the concrete trestle is of such great weight that it cannot be used in very soft and marshy ground, unless there is a subsoil that is capable of sustaining the weight of the bridge. We have found, in our experience, that we have to restrict its use to locations having subsoils containing gravel, stiff clay, or sand, and that black, marshy soil will not carry these trestles safely.

Mr. I. F. Stern, M. W. S. E.: The Chicago & Northwestern

Railway Co. had the first installation of concrete piles in the West, I believe.

The plant that was installed in Racine, Wisconsin, was for our company, and the piles that Professor Talbot detailed were made in that plant. The conditions under which we used concrete piles there were slightly different from those for which Mr. Cartlidge has designed his trestles. At Racine we had a 250 ft. draw-span. The old bridge had high masonry abutments, and comparative estimates showed that it would be cheaper to put in piers for flanking spans with small buried abutments in the embankments provided we could get proper foundation in the bank. We decided to use the Chenoweth pile, and let the contract on that basis. We drove the piles there and they gave what we thought was good satisfaction. I have since come to believe that the proper thing to do in a case of that kind is not to use concrete piles but to put in a spread-foundation. I think if conditions similar to that come up again we would not use the concrete piles. We found the same trouble that Professor Talbot noted, that the pile would *broom*—if I may use that expression of a concrete pile—on the ends where it had been filled in, or cast on. I see that Professor Talbot made tests, cutting the ends off, and I have just been informed that this has been done by the Sanitary District, at a cost of $8.00 for fifteen piles. This certainly shows that the idea is practicable. However, the point of the pile is also cast on to it and I do not think one would want to cut that off. We found, as I said, considerable *brooming,* but, on the whole, the piles did very well. Of course the condition was a bad one and we could not give the piles proper time to season; we had to drive them within about three weeks after they were cast. The manufacture of this style of pile seems to be a very simple operation, and as every step of it is open to absolute visual inspection, one may feel assured that he has a good pile and something entirely different from the case that the Chairman has mentioned, where a long slender shaft is filled with concrete from the top. I think that point has been very well stated.

It occurred to me, in reading Mr. Cartlidge's paper, that there is a likelihood of encountering one difficulty, in driving this kind of pile, that is often found in driving wooden piles; that is, a pile-driver estimates that a pile can be driven to a certain depth, but a boulder is encountered and the pile will project a foot above the track. In the case of a wooden pile, it can be sawed off and if a train comes along it is not delayed for any length of time. With a concrete pile, the case would be quite different. I will ask Mr. Cartlidge if he has ever had such an experience?

Mr. Cartlidge: We have that experience quite frequently, but we do not find it so difficult to cut off the concrete piles as has been anticipated. I have had that question asked me a good many times, in correspondence, about concrete piles, and I have always replied that we have no difficulty in cutting them off. With the Chenoweth pile the task is more difficult than with the cast pile because of the presence of the netting, but with two men it does not take to exceed half an hour to cut off a pile. It simply means chipping through the mesh until the bars are reached, and sawing them through—a very short operation; then it is an easy matter to chip off the rest of the concrete. The piles are generally so green—as they are not over a month old when driven—that they have not the strength of a thoroughly seasoned pile, and it is not as difficult a task as might be expected.

Mr. Stern: We have not used any of these reinforced-concrete slabs on our road. For a long time we were partial to what we call a T-rail concrete-culvert and the I-beam concrete-culvert, which is in some cases practically a concrete trestle, because we build as many as three or four spans, sometimes up to 20 ft. in length. We depend upon the I-beams for giving strength and encase them in concrete for protection. We do not figure upon the added advantage of the structure as a reinforced-concrete structure, although at a recent meeting of this Society it was pointed out that there was an added element of strength. We like to go up rather high in the unit stresses that we allow in the steel, and if through faulty construction or the effect of moving loads vibration is caused sufficient to dislodge the concrete, the structure will still be absolutely safe and our trains would not be in danger. We are approaching, in fact, the idea of some designers on reinforced-concrete structures of putting in an auxiliary system of steel which is stressed up very close to the elastic limit, although I have not seen many evidences of that system being put in. Of course, with the trestles that we speak of, the I-beam concrete-culverts, and the T-rail concrete-culverts, we may have quite a spread-foundation, so that we can build the trestles on almost any soil, and the objection that Mr. Cartlidge has brought out of not being able to build his concrete trestle on any but gravelly soil is overcome. In Chicago, some years ago, we had occasion to put in a spur track to a manufacturing plant, where we put in a reinforced-concrete structure, and we built practically a concrete trestle, except that we did not use concrete piles, building small piers—rather thin piers—and that is the same thing that we use in the I-beam concrete-culverts referred to. In this case we had about a 13 degree curve, and while the trains operated over that on very low speed, we found no difficulty in maintaining our construction and having the trestle give absolute satisfaction.

Mr. Condron: Was that slab reinforced with bars or was it an I-beam bridge?

Mr. Stern: There was some bar-reinforcing. We have no objection to putting in bars in places where there are practically quiescent loads. Our objection to bars has been where there are high speed trains and consequent vibration.

Mr. Condron: Vibration, you mean, while the slabs are green?

Mr. Stern: Unfortunately we have to run our trains over the slabs while they are being put in. Then outside of that, of course there is always the question of water percolation through these slabs. It seems absolutely impossible to get an ideal protection so that water will not drip through, and if we have a construction where we can depend upon our steel, we feel a good deal safer on account of it.

Mr. Cartlidge: Mr. Stern spoke of the use of spread-foundations in the concrete-pile abutments. Our experience has been somewhat similar,—that it is necessary on a new bank to use a spread-foundation or wooden temporary foundation rather than to put in a permanent foundation. Our practice is now to allow a bank to settle for the life of a wooden pile pier—perhaps twelve or fifteen years—and we find that in general by that time the banks have reached their limit of settlement and we can then put in a concrete pile abutment at very little cost, which will, we suppose, last indefinitely.

With regard to the question of I-beam culverts, we have had some little experience with those. Our first large culverts were built in that manner. Our experience with percolation in concrete and I-beam culverts has been such as to warrant, it seems to us, the use of reinforced-concrete instead. The presence of water heavily charged with rust in streaks parallel to the I-beams, and apparently coinciding with them under deep fills, is quite conclusive evidence that there is some corrosion of the beams, while in our reinforced-concrete culverts with equal span and under equal fills we have no signs whatever of corrosion, although there are some cracks. In our trestles we have no indication of percolation. The waterproofing which we put on seems to be *waterproof,* and the drainage takes away all water pressure.

Mr. Condron: As to the structures in which the I-beams have been imbedded in concrete, I think that rust-marks under such structures are very generally observed, showing that water does find its way down between the concrete and the I-beams. That has been very noticeable in a number of the Melan concrete bridges which have been built with riveted trusses in arch form. By looking under those structures it will be found that the steel members in them can be located by the rust-stain on the concrete underneath, and it is quite reasonable to believe that some water will find its way through such structure in well-defined paths, causing the metal to rust, notwithstanding the protection which the concrete is supposed to give it. The smaller sections of steel in the form of bars are generally more distributed through the concrete, and if bars are placed transversely as well as longitudinally in reinforced-concrete slabs or arches, these will bind the structure together and prevent the formation of lines of cleavage, or cracks longitudinally with the structure. If the cracks cannot form, the steel will be protected.

Mr. Stern: We do tie the slabs together laterally by putting in a steel bridging. We use half-inch bars that come in over the top flange of one I-beam, with a hook on that side, and come down under the flange of the next I-beam and then up on to the third I-beam, with the end left plain. These are then forged or heated in the field and bent down over the third I-beam. Then we go from the top of the middle I-beam under the third I-beam, and so on.

Mr. Condron: They are x'd between them?

Mr. Stern: They are x'd between them to tie them together laterally.

Mr. Condron: I should think that to run the bars directly under the I-beams, and, for that matter, other bars over I-beams, the full width, or as much of the width of the structures as possible, imbedding them in the concrete, would be a much more satisfactory method, much less expensive, and give better results. I also think there would be less danger of cracks. The bars would be where they would be most efficient and the cost of the bending and of the forging would be saved. This method, if there is anything in the whole theory of the adhesion of steel and concrete, would give the results that we are after even better than by the bending.

Some years ago I made some rather interesting tests to determine how far a bar would slip in concrete before it would come against a shoulder of the kind mentioned, and found that with imbedment of twelve inches in concrete, even corrugated bars or twisted bars would move enough to break the bond of the concrete, before they would develop a bearing against an adjacent piece of steel, while by imbedding those bars twice that length in the concrete alone the bars could be broken without moving them at all. The occasion of those tests was to try out a form of a mechanical splice for arch bars, and I failed to find any mechanical splice which was at all equal to the mere bond or adhesion of bars in the concrete, although some of those splices were of an expensive type. I think it will be found that by running the bar further along, expending the same amount of money or less, in additional length of bar imbedded in concrete, more positive results will be obtained.

Mr. Layfield: Referring to the question of the weakness of the pile at the top, I do not remember whether any of the statements indicated how far that exists, but I notice that in Mr. Cartlidge's drawing the pile is imbedded—I think it is ten inches—at the top.

Mr. Cartlidge: A foot, I believe.

Mr. Layfield: It seems to me that would very largely overcome any trouble that might be expected to result from weakness of the pile at the top. Of course, the pile is not weakened in the same sense that a wooden pile is weakened when *broomed.*

Mr. Condron: Mr. Cartlidge says the piles are usually imbedded about one foot in the concrete cap.

Mr. Layfield: Yes. Wouldn't that provision overcome the difficulty that has been referred to?

Mr. Condron: Mr. Cartlidge stated, in reading his paper or describing the pile, that he thought that method would overcome the difficulty.

A Member: I want to ask Mr. Cartlidge what his experience has been as to expansion and contraction of the slabs?

Mr. Cartlidge: We make provision for expansion and contraction by leaving half an inch between the ends of the adjacent slabs, making each span half an inch short of the length center to center of bents and fill that in with soft mastic.

A Member: Has any observation been made as to what the expansion is?

Mr. Cartlidge: We find it necessary to make adequate provision for expansion. We found in some cases after setting the slabs in mortar—the weight being very great and the mortar of course setting very hard and with complete adhesion—that the contraction of those slabs in a long trestle would actually pull the concrete apart over the bearing in fine cracks extending longitudinally upward from the bearing toward the center support, or the line through the center of the cap, in a direction contrary to that of shear or tension in the concrete, showing that there was a force there which could only be explained on the hypothesis of contraction. In order to overcome that we now put under our slabs a thin sheet of zinc to which concrete or cement will not adhere. This provides a slippery surface on which the slabs can ride.

A Member: Do you put it under every bent?

Mr. Cartlidge: Yes, we put it under every bent; both ends of each slab.

Mr. S. T. Smetters, M. W. S. E.: I have here the record of the driving of piles by the Sanitary District, under the abutments of the Chicago, Milwaukee & St. Paul Ry. bridge at Central Street in Evanston. The abutments were built high above the water-line, and that is the reason for using the concrete piles. Forty piles were driven under each abutment. The time for actually driving the piles was from nine minutes—the minimum—to twenty-seven minutes—the maximum. The average number of blows for the minimum was about 600, and for the one that required twenty-seven minutes 1782 blows were required. The minimum time to drive any pile—from one pile until the next one was driven—was twenty-one minutes. The pile driver used was a pair of leaders or guides swung from a stiff-legged derrick. There was an extra line on the boom to handle the pile, the piles weighing, I think, three tons, if I remember right. It requires only a small force of men to do the work, and the concrete piles were handled as rapidly as wooden piles. The maximum number driven in one day was twenty-one, there being no way of getting a higher speed than that, because in part of three days they would drive the entire abutment. After driving about nine piles it was noticed that they commenced to rise, and in that way we found that we would have to cut off a number of piles. That was the reason we had to cut off the fifteen piles Mr. Stern mentioned, at a cost of $8.00. In cutting off those piles, we commenced with a sledge and battered off the concrete, and we noticed that there were no lines of weakness developed by the driving. One of these piles required 1600 and some odd blows to drive it, and the concrete was solid throughout. We cut off about a foot and a half of this pile. It was not necessary for us to cut off the bars because the concrete was bedded around them, and all we needed to do was to bend them down. The concrete cap that went over the top was so shallow we could not allow the piles to project more than eight or ten inches in the slab. The cost of these piles to the Sanitary District was something like $37.50 apiece. The price given now is usually $1.00 per foot for a 14-in. pile, delivered in Chicago.

I would like to ask Mr. Cartlidge where the plant shown in the lantern slide view was located.

Mr. Cartlidge: The view showing the machine is that of the Racine plant for the C. & N. W. Ry. Co. The other views are those of the Hannibal plant of the C., B. & Q. R. R. Co. We did not have a view of the complete Hannibal plant but did have one of the Racine plant, so I showed that as a typical plant.

I might say that our practice on the Burlington has been generally to omit the pointing of these rolled piles. We head them in order to provide a hard surface for the hammer. They are driven with tips just as they come from the rolls, with the lower end partly hollowed out, and we have had no difficulty in getting them down.

Mr. Condron: The rolled pile has a much rougher surface, of course, than the moulded pile. Of course, if there is anything in the adhesion of the soil, that would be increased in the rolled pile.

Mr. Smetters: I do not think that was the case with those of the Sanitary District.

Mr. Condron: Were they smooth?

Mr. Smetters: They were painted. We required them to be first class in every respect. I think they took pains with our work.

Mr. Condron: That reminds me of a story that one of the bar companies' representatives told. A sample was submitted with a bid for a particular form of reinforcement for a government job and the bid was afterwards accepted. In order that the sample should look artistic to go into the government engineer's office it was painted with dull black paint and the ends were nickel-plated. The contract called for the reinforcement to be up to sample, and when the material arrived the government inspector required that every one of the bars should be painted before allowing them to be put into the work. I do not think, however, that he required the ends to be nickel-plated!

Mr. A. C. Warren, M. W. S. E.: In connection with the waterproofing of this work, I wish to inquire if the Portland cement used in connection with kerosene and tar has any cementing or chemical qualities, or if it is used merely as an equally fine ground inert material might be used, more as a body?

Mr. Cartlidge: My opinion is nothing but an opinion. I do not *know* anything about it. The formula for this material was taken from the *Engineering News* and was given to that paper by a naval officer who was stationed at Pensacola and had used this mixture and another one in painting some corrugated sheds which were exposed to the salt spray, and had found this material useful in that way. We adopted it for use on our bridges to protect them against the drippings of brine. Our theory as to the cement is that it is an agency for neutralizing such free acid as exists in the tar and possibly also takes up some water which exists in the tar or kerosene, and which might help to disintegrate the paint if it were left in. As a matter of fact, we have this paint made at a factory which provides us with our standard paint, and sometimes several months elapse before it is used; the cement is then hydrated and in the bottom of the barrel; but it does not seem to affect the quality of the paint, so we have assumed that its purpose was not as a thickener or as a pigment but simply to provide a neutralizing agent. With tar paint it is a common thing to add lime or some other alkali to neutralize the free acid which I believe always exists in commercial tar.

Mr. Stern: I should have stated, when I spoke of those I-beam concrete-culverts, that we put in 3-in. No. 16 expanded metal running the entire length of the slab under the beams. I do not think we have seen the phenomenon which has been mentioned of a line running along showing the crack of the concrete, under any of our structures. In the earlier cases where we did not take proper pains in waterproofing, we occasionally had dripping of water, but I have attributed the sticking or holding up of the concrete to the under side of the pier to the expanded metal as much as to any other one thing.

Mr. Strehlow: There is one arch bridge of Melan construction that I think is an exception to those mentioned; that is at South Bend, Indiana, across the St. Joseph river. The exception is probably due to one, two, or three reasons: One is that the Melan ribs were coated with milk grout which would protect them from rust; the second is that there is an excess of sand used, being gravel and sand mixed, just as it came from the pit; the third reason may be the care that I insisted upon in placing the concrete. I have never seen any rust marks under the ribs.

Mr. Condron: Did any longitudinal hair-cracks appear?

Mr. Strehlow: The bridge has been completed about four years. About a year ago I was going to examine it but the snow was nearly four feet deep and I could not do so; but six months after it was in place I did not notice any longitudinal hair-cracks.

Mr. Condron: Were there open lattice arched trusses in that bridge?

Mr. Strehlow: Yes.

Mr. Condron: And you had bars laterally?

Mr. Strehlow: Very light lattice work.

Mr. Condron: You also had transverse bars between those trusses?

Mr. Strehlow: No; we had very light straps—just a spacing from one rib to the other, about three feet long.

Mr. Condron: The subject of proper design or methods of design of reinforced-concrete structures is, of course, a feature of this work as of other work, but I presume that the structures of the Burlington road have been built on the same methods of design referred to in Mr. Tebbett's paper on track-elevation work. It is of interest in this connection, though, to note the fact that at the recent convention of the Maintenance of Way Association a recommended practice was adopted for the design of reinforced-concrete structures. For railroad structures, where impact stresses from moving loads are added to the dead and live load stresses, the allowable unit stress in tension for structural steel bars is 14,000 lb. per sq. in.; for high-carbon steel bars is 17,000 lb. per sq. in.; and for concrete in bending compression, 750 lb. per sq. in. There are a number of other recommendations to which I might call attention, but I think it is important for us to begin to have some recognized unit-stresses for combinations of steel and concrete.

Mr. Smetters: Could you use broken stone in making the concrete piles?

Mr. Cartlidge: The use of broken stone or gravel is optional, of course, with the engineer. In general it is preferable to use gravel, for the reason that it finds its place more easily and rolls up more readily in the pile. The same is true of the molded pile, but there is no reason why stone cannot be used. As a matter of fact, we do use stone in most of the piles in our work.

Mr. Smetters: In the molded pile there is some moisture, but the rolled pile is very dry.

Mr. Cartlidge: Yes, but we use stone frequently. In Kansas City we are using nothing but stone.

Mr. Smetters: Has anyone here had any experience with the Raymond concrete pile molded in place?

Mr. F. E. Davidson, M. W. S. E.: In what way?

Mr. Smetters: I would like to know what result was obtained after pouring the concrete.

Mr. Davidson: The very best result. I would consider the method of driving the Raymond pile as almost an ideal condition. The core being driven in a steel jacket, it is possible to examine the hole before the concrete is poured. Personally I like that method of making a concrete pile, and rather prefer it to the making of a molded pile. That is, however, my own personal opinion. One knows exactly what he has, as he can inspect the hole. There is no chance of breaking off or *brooming.* It is then only a question of properly placing the concrete.

Mr. Condron: This is done, as is well known, with columns for buildings, and the hole is inspected—to use the term—but nevertheless almost invariably when the forms are taken off the column, more or less defects are found. If the work has been sufficiently well taken care of the defects are insignificant, but in some cases a block of wood, a lot of sawdust, some dirt, and various other things have gotten down into the column form; that is a matter of serious consideration in concrete columns in buildings, and requires most careful attention. So that even the inspection of the hole may not insure a perfect filling of the form from the top. I am not offering that as a criticism necessarily to the Raymond pile, but am simply calling attention to what I have observed in building-columns.

Mr. Cartlidge: I am inclined to agree with Mr. Davidson in one regard,—to a certain extent at least,—that the Raymond pile has advantages which no other pile has. It is possible to drive a Raymond pile in situations which will not permit of driving any other pile, and the fact that reinforcement is seldom used in a Raymond pile makes it a much more simple matter to obtain perfect concrete or good concrete than it is in a column in a building or a reinforced column of any sort cast on end. On the other hand, like everything else, no one device is good for all situations, and my idea with regard to the Raymond pile is that some situations, having a very tough and leathery soil,

—such as that on the Evanston channel, for instance,—resulting in the lifting of the pile itself, would be apt to be disastrous to a pile cast in place and seasoned while others are being driven. I have heard of cases in which examination disclosed the fact that the pile had been sundered by the upward pressure of the ground. On the other hand, there are places where nothing but a Raymond pile could be used and a molded pile cannot be driven with any success at any reasonable cost. I believe that each kind of pile has its proper place.

Mr. Smetters: I would like to ask Mr. Crocker if he is familiar with the work of driving the piles for the Denver Auditorium. I understand there is great likelihood of encountering boulders in and about Denver. The Raymond people claim an advantage in driving their pile where there are boulders because they have and use the protected shell.

Mr. H. S. Crocker, M. W. S. E.: All I know about the Denver Auditorium piles is what little I saw in passing by the work, when in progress. Those piles were driven in gravel and I do not believe any boulders were encountered. The necessity of piling was not great.

Mr. Smetters: In other words, you think the foundation was sufficiently good without the piles.

Mr. Crocker: They had a very good foundation without piles. Of course, the piles did no harm.

Mr. Davidson: I remember a very important building on the North Side where the state of the ground was such that probably the only foundation that could be put in satisfactorily was a system of Raymond piles. A series of test-borings was made which showed that the building site was directly over an old sand-hole,—that is, an old hole where sand had been taken out years ago and the hole had been filled up with rubbish, tin cans, etc., of every description; in fact, as far down as twenty-two feet, rubble stone and boulders were found; almost everything had been dumped in there. The question was, what kind of piling to use there. In taking the matter up with some of my associates I decided that probably the most satisfactory foundation we could put under that particular building was a system of Raymond piles. They drive the shell with a steel core and they assured us that they could drive through anything in that hole.

I agree with Mr. Cartlidge that in a great many cases it is preferable to use some other kind of pile, particularly in soil such as is along the Evanston channel. In that case the Raymond pile should be reinforced, but in building-work in ordinary clay or sand I do not think it is necessary to reinforce the pile itself.

With reference to the waterproofing of reinforced-concrete slabs for railroad bridges, etc., where it is necessary to waterproof them, has any one had any experience with the use of a waterproofing-compound made of hot pitch and Portland cement,—that is, the cement is added to the pitch when at a temperature of about 250 degrees, and is then applied hot in a plastic condition? I would like to know if anyone has had any experience with that method of waterproofing.

Mr. Cartlidge: We have not tried Portland cement with hot pitch but we have tried a mixture of fine sand and hot pitch on our track-elevation, without success. The difficulty seemed to be that it could not be made sufficiently elastic to stand cold weather and at the same time of sufficient stiffness to withstand heat and not flow, the result being that at the joints and sometimes in other places there were cracks which allowed the water to go through. Our remedy for that was to put on waterproofing, as has been described, of burlap and asphalt. We find that nothing we have tried, with only one exception, will adhere to concrete except this tar paint. That one exception is a patented article that is on the market at a considerably higher cost.

Mr. Davidson: I will state, for the benefit of the meeting, that my authority for the statement that that was a waterproofing-compound was Captain Reed, of Detroit, the president of the Reed Wrecking & Navigation Company. I met the gentleman last week in Buffalo, had a long talk with him, and he told me he was using it and had used it in place of oakum in battening down hatches on a number of lake vessels, and he says the compound is absolutely waterproof; that it is pliable, will not crack, and will stand any kind of usage, and he is my authority that it is absolutely waterproof. I have never tried it personally. He says he uses about one-half Portland cement, mixes it with hot pitch, and applies it when hot.

Mr. Strehlow: I would like to ask if those are wood or steel hatches.

Mr. Davidson: Both. He said he used it on both steel and wooden vessels. Captain Reed is an authority on work of that character.

DIVERSITY FACTOR IN THE DISTRIBUTION OF ELECTRIC LIGHT AND POWER.

H. B. Gear, M. W. S. E.

Presented March 23, 1910.

In the distribution of electricity over a large city for lighting and power purposes, the maximum demand of the day upon the distributing-system varies from day to day during the week, and from month to month during the year. The varying length of the day due to changing seasons, the habits of the population served, and the character of the district—whether residence, mercantile or manufacturing—combine to produce this situation.

In residence districts, for instance, the use of light is such that the maximum demand comes at about 7:00 p. m. in winter and at 8:30 p. m. in mid-summer, as shown in the load-curves in Fig. 1. In outlying business districts in the large cities, and in the central business districts of the smaller cities, the maximum demand comes from 5:30 to 6:00 p. m. in winter, or at 8:30 p. m. in summer. It is usually heavier Saturday than other nights of the week. In the central business districts of cities like Chicago, the maximum demand comes from 5:00 to 5:30 p. m. in winter, and at various other hours in summer. Here the Saturday load is less than that of other days because of the early closing of offices and shops that day. This is also true of manufacturing districts where the load is chiefly power. In a purely manufacturing district, the maximum load occurs at about 10:00 a. m., the afternoon load being from 15% to 20% less than the maximum of the morning. The load-curve in Fig. 2 is that of a power-circuit which carries some lighting and so has a 5:00 p. m. maximum.

In the larger cities the conditions vary in all of these classes of service more or less with the character of the population. The habits of the people in the foreign-populated wards are different from those bordering on the boulevards, and the requirements of dwellers in apartments are different from those living in houses. In the outlying districts of Chicago, stores are closed Wednesday and Friday evenings, while in downtown districts very few stores are open evenings at all and the use of electricity is limited largely to show-window and display lighting. During the summer the loss of demand in residence districts is partially made up by the requirements of the pleasure parks. The combined curve for these various classes of service is shown in Fig. 3.

The combined effect of all these influences is to produce a smaller maximum demand at the generating-station than elsewhere in the system. That is, the sum of the maximum demands of the transformers and distributing-mains is greater than that of the feeder. The sum of the feeder maxima is greater than that of the substation and the sum of the substation maxima is greater than that of the generating-station.

The ratio of the sum of the maxima of the subdivisions of the distributing-system to its actual maximum demand as observed at the point of supply is called the *diversity-factor.* Thus, if the sum of the individual maximum loads on the ten feeders of a substation is 1200 kw., and the coincident maximum of the feeders is 1000 kw., the diversity-factor is $\frac{1200}{1000}$ or 1.20.

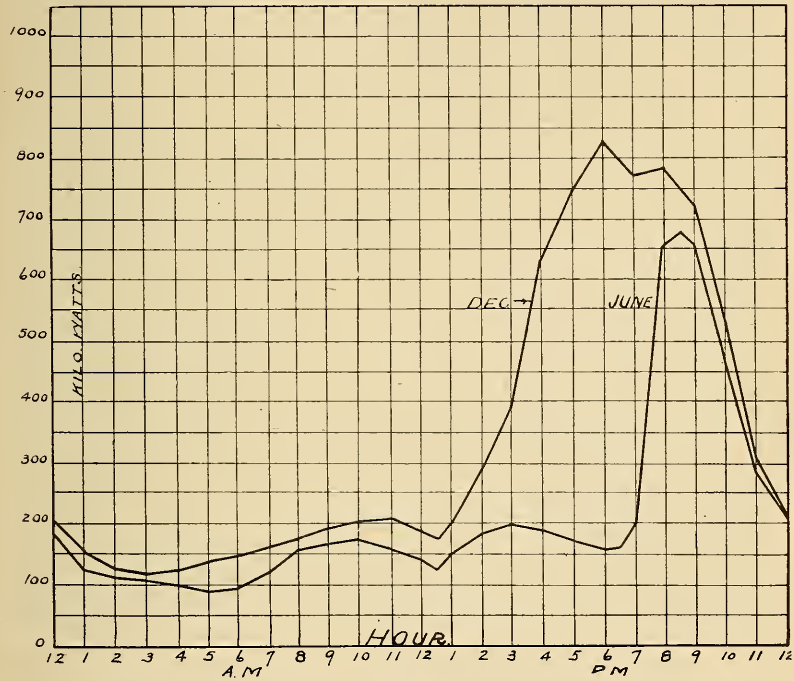

Fig. 1.

The study of diversity-factors is of great importance from a commercial point of view as well as being an interesting engineering problem. The investment required by the central station company in the various parts of its operating system for each kilomatt of maximum demand determines the fixed charges which must be considered in determining costs and in making an equitable system of rates.

October, 1910

The existence of a diversity-factor between the demands of a large number of consumers permits the central station company to supply their demands with a much smaller investment in generating-capacity, and at a lower cost of production than would be possible if these consumers were operating individual generating plants. This difference must be sufficient to enable the central station to add the financial burden of a distributing-system and yet have a margin upon which to sell its product economically to its consumers. The effect of the diversity-factor is therefore a subject of interest to both producer and consumer of electricity.

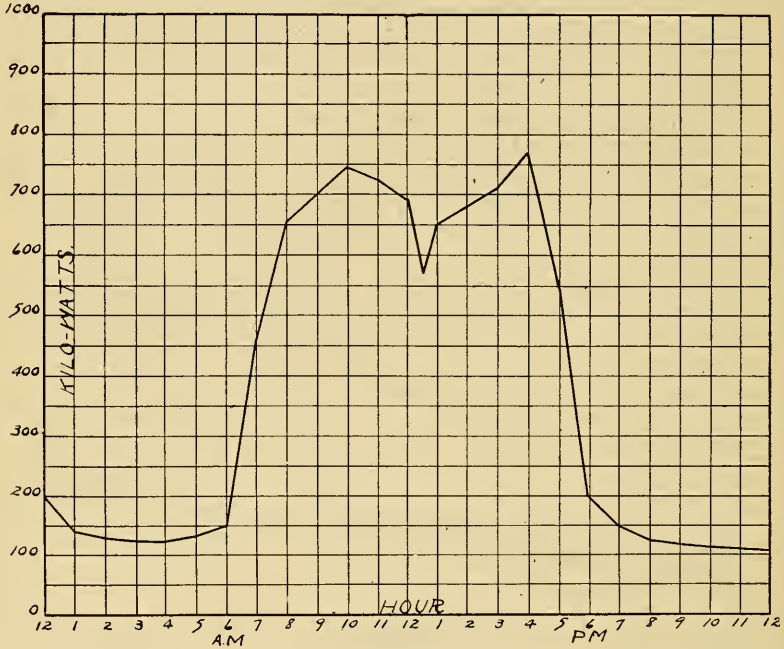

Fig. 2.

The larger the system the greater the diversity-factor, and the study will cover an alternating-current system supplied by substations, feeders, mains, transformers, etc., as shown in Fig. 4. An alternating-current system has been selected for analysis as it is somewhat easier to observe than a direct-current low-tension system because of the presence of transformers whose load may be measured. The loads on the distributing-mains of a low-tension feeder are not so easily measured, and observations, therefore, cannot be readily made.

The consumer being the originator of the demand for electricity, the development of the diversity-factor proceeds logically in the reverse direction from the flow of energy.

Observations made in residence districts supplied by overhead lines indicate that the sum of the maximum demands of individual consumers is from two and one-half to three times the coincident maximum demand on the transformer, the ratio being lower where there are less than ten consumers on a transformer and higher where there are more than thirty.

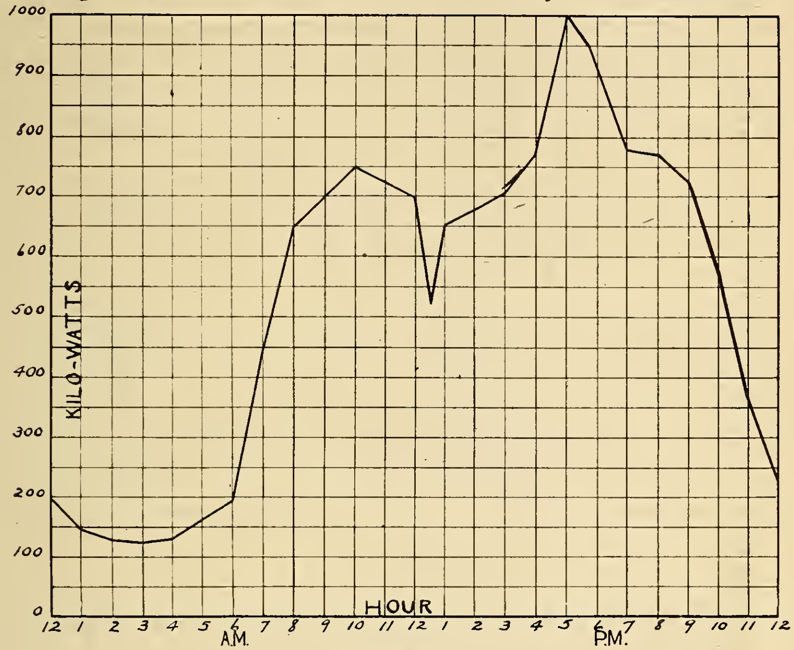

Fig. 3.

In commercial districts with numerous small stores which are supplied by overhead lines, as illustrated in Fig. 5, the coincident demand is much higher in proportion to the consumer's demands.

The ratio of the sum of consumers' maxima to the coincident demand in this class of lighting is found to be from 1.5 to 1.7, it being lower where there is considerable display-lighting, show-windows, etc., and higher where the shops are of such a character that not all the lighting is needed continuously.

In the block of commercial-lighting shown in Fig. 5 there are 55 customers, 26 services, and 1200 lights connected. The measured demand on the transformer at 7:00 p. m. Saturday is 34 kw., while the sum of the readings of the demand-meters is 55 kw. The diversity-factor is therefore $\frac{55}{34} = 1.6$. The sum of the demand-meter readings is $\frac{55}{60}$ of the connected-load.

In the densely populated residence block in Fig. 6 the connected-load is 2100 lamps, or 105 kw. The consumers' maximum demands aggregate about 63 kw., and the coincident maximum as measured at the transformer is 18 kw. There are over 175 consumers connected to the transformer. In this case the diversity-factor is $\frac{63}{18} = 3.5$ and the consumers' demands are $\frac{63}{105}$ of the connected-load.

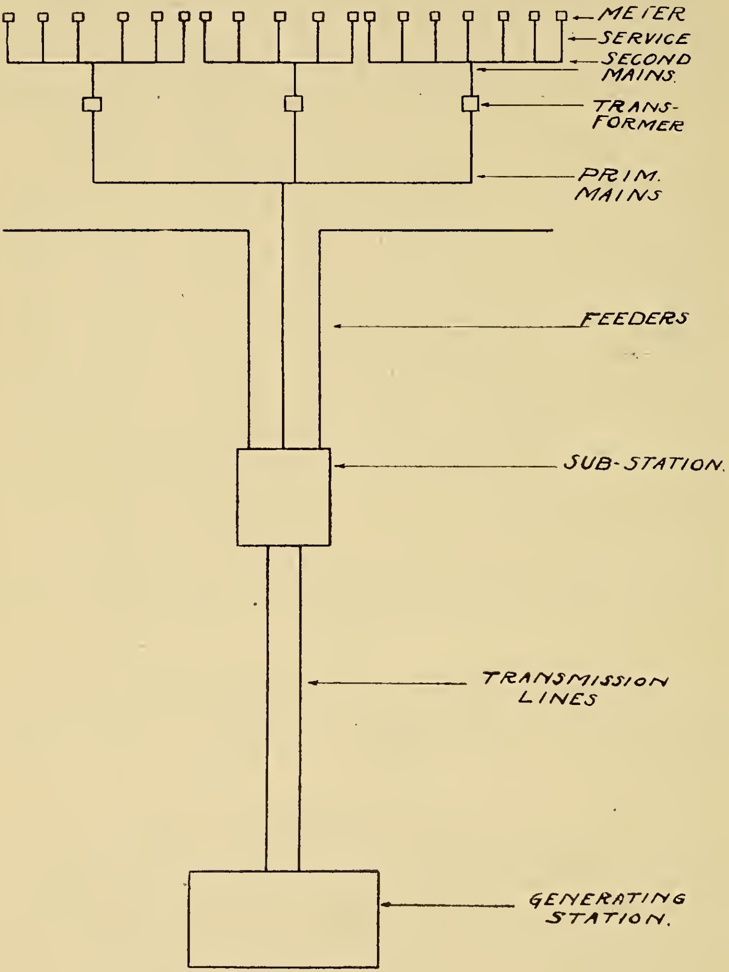

Fig. 4.

This probably represents as dense a condition as would be found anywhere in a residence district. It is due in this case to the fact that the block supplied by this transformer consists entirely of three-story apartment buildings, in which about 90% of the tenants are using electric service.

Power consumers are not often grouped so that any considerable number can be supplied from one transformer installation. They must be kept separate from lighting, and therefore usually require a separate set of transformers for each consumer where the load is 2 hp. or more. In large installations advantage is taken of the diversity between meters to reduce the transformer-capacity installed. This cannot be done with small consumers except in the occasional situations where several power-consumers are located within a radius of about 500 ft.

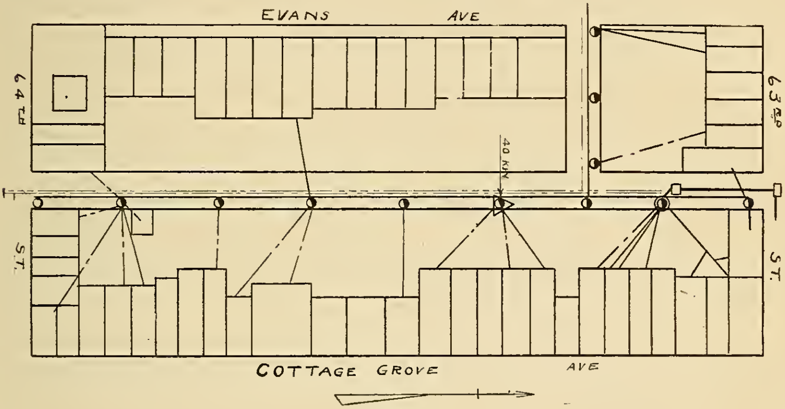

Fig. 5.

The diversity-factor between meter and transformer on power customers is therefore very small and probably does not average over 1.1 for all power installations.

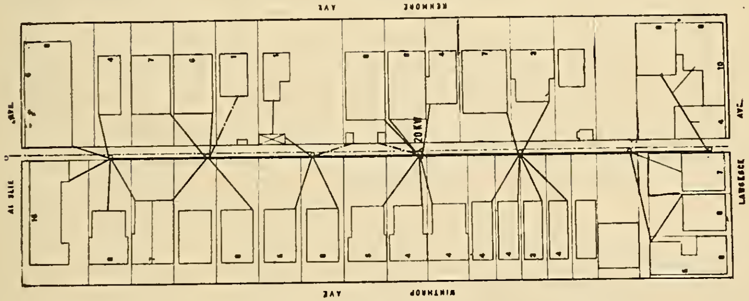

Fig. 6.

Advancing toward the substation, the next point at which diversity may be conveniently observed is at the feeder switchboard. There is a considerable diversity-factor between the sums of the transformer maxima and the maximum feeder-load.

The factor varies with the character of the territory served and with the density of the load. In scattered residence territory, where there are many 1, 2, and 3 kw. transformers, and few larger than 15 kw., the ratio of maximum feeder-load to total transformer capacity is from 45% to 50%. In territory where transformer units vary from 5 to 30 kw., or larger, the ratio is 55% to 65%. In commercial districts with transformers from 5 to 50 kw., the ratio is from 75% to 85% or higher.

Assuming that each transformer carries its rated load at some time during the year, the diversity-factor for a feeder in scattered territory is from 2 to 2.2. In denser territory the factor is 1.6 to 1.8, while in commercial districts it is 1.2 to 1.3.

On circuits carrying a scattered-load power in units of 5 to 100 hp., the ratio of maximum load to transformer-capacity is from 45% to 50%, which makes a diversity-factor of 2 to 2.2. Where a few large power customers, ranging from 100 to 500 hp. or more, are on a separate feeder, the ratio is from 75% to 85%, making a diversity-factor of 1.2 to 1.3. These ratios shift somewhat in a growing system, the tendency being to reduce the diversity-factor as the territory becomes more densely built up. They are also modified somewhat by the losses on feeders and mains, which may be as much as 15% to 20%.

In the substation there is a diversity-factor due to the difference in the character of the load carried by the different feeders. The maxima on the power-feeders occur during the daylight hours, while the maxima on lighting-feeders vary from 5:30 p. m. in commercial-lighting to 7:00 p. m. in residence-lighting.

With three-phase distribution there is a diversity-factor between phases where the lighting is carried single-phase. The net result is that in a substation with ten or more feeders the diversity-factor averages about 1.15. In the substation supplying power-feeders and general lighting it is likely to be as high as 1.2, while in a residence district with little power-load it is about 1.1.

Having thus analyzed the diversity between the various elements of the distributing-system, it is of interest to derive the total diversity-factor from substation to consumer for various classes of business. For convenient reference the following table of diversity-factors will be useful:

TABLE 1.

	Residence.	Commercial Light.	Scattered Power.	Large Users.
Substation to feeders.....	1.15	1.15	1.15	1.15
Feeders to transformers...	1.8	1.25	2.0	1.25
Transformers to meters...	3.0	1.6	1.1	....
Total diversity-factor ...	6.20	2.30	2.53	1.44

From this table it is apparent that the total diversity-factor for residence lighting is 6.2, for commercial-lighting 2.30, for scattered-power 2.52, and for large users of light or power 1.44. The latter figure would apply to consumers requiring from 100 to 500 kw. The combined diversity-factor of systems giving all of these kinds of service should range from 2.5 to 3.5, depending upon the relative proportion of each kind served.

These factors may be illustrated by a concrete example:

Assume a residence district, well settled, in which the sum of consumers' demands during the heaviest month of the year is 100 kw. The transformer-capacity required to carry the coincident demands of these consumers will be $\frac{100}{3} = 33.3$ kw. The feeder-capacity required will be $\frac{33.3}{1.8} = 18.5$ kw. The substation capacity required will be $\frac{18.5}{1.15} = 16.0$ kw.

Similarly, the capacity required for a commercial-lighting district in which the sum of the consumers' demands is 100 kw. will be 43.5 kw., for scattered-power it is 39.5 kw., and for large light or power consumers it is 69.5 kw.

This reduction in the amount of capacity required in generating and distributing equipment makes a corresponding reduction in fixed charges which form a large part of the cost of producing electricity. The investment-cost is further reduced by the ability to use large generating-units, which cost less than half as much per kilowatt as the cost of generating-machinery in the sizes commonly used for independent plants.

The merging of all these demands has also a pronounced effect on operating costs, in that the load-factor of the generating-station and distributing-systems is very much higher than that of the consumers who take their supply from it. This permits the station to be run at an economical load a large part of the time, thus reducing both labor and fuel-cost per unit generated.

The combination of these economies constitutes the central station's justification for existence, and it is unnecessary to add that the justification is well nigh complete in these days of steam turbines and 20,000 kw. generating-units.

Thus far the point of view has been from the consumer toward the central station. It is important, however, that the situation be seen from the point of view of the central station toward the consumer, as the diversity-factor has a very marked effect upon the investment accounts which must be carefully considered in determining the cost of rendering the different classes of service.

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Stated in the reverse manner for each 100 kw. of substation capacity used to supply residence-lighting, the central station company must provide 620 kw. of meter-capacity, 207 kw. of transformer capacity, and 115 kw. of feeder-capacity. In serving large light or power customers, it must provide 144 kw. capacity in meters and transformers and 115 kw. in feeder-capacity for each 100 kw. of substation capacity.

The diversity-factor for small and scattered consumers is higher than these figures, and these consumers require more equipment and a larger investment than is required for the consumers in thickly-settled districts.

The investment required per kilowatt varies considerably with the type of construction and the geographical situation of points of supply and delivery. It is considerably more for underground lines than for overhead, and no figures can therefore be given which will have great value for other systems than the one to which they apply.

It may be instructive, however, to give some figures to show, in a general way, how the investment is distributed between various parts of the system under a set of assumed conditions which are fairly representative.

Assuming the average cost of a meter at $10.00, line transformers at $7.00 to $10.00 per kw., transformer substations and transmission lines at $35.00 per kw., and generating-station capacity at $150.00 per kw., the investment is divided approximately as follows:

TABLE 2.

	Scattered Power	Scattered Residence	Dense Residence	Commercial Light	Large Users
Generating capacity	37.0%	18.5%	30.0%	44.5%	60.0%
Trans. line and sub-sta.....	9.0%	4.5%	7.5%	10.5%	14.0%
Feeders and mains	49.5%	52.0%	26.0%	35.0%	23.0%
Transformers	4.0%	4.0%	2.5%	3.0%	3.0%
Meters	0.5%	21.0%	34.0%	7.0%	negligible
Total	100.0%	100.0%	100.0%	100.0%	100.0%
Investment per kilowatt of annual maximum demand on generating station..	$410.00	$820.00	$500.00	$350.00	$250.00

It is apparent from these figures that as far as that part of the cost of electricity-supply which depends upon investment is concerned, small and scattered consumers are the most expensive to serve. This is due chiefly to the large investment in meters and distributing-mains. For instance, the cost of meters in residence lighting is about 25% of $820.00 or $205.00 per kw. of station demand. This means that if all the consumers were of this class the company would have as much money invested in meters as in generating-plant.

The commercial lighting and power business, where the diversity-factor is smaller and the consumption demand larger, requires a less meter-investment and a greater investment in generating and substation capacity.

The maintenance-cost of a large meter and distributing equipment, and the general expense items of meter-reading, billing, etc., are correspondingly high for small consumers, so that it is probable that the outlying parts of the distributing-system are served at a loss during the earlier stages of development.

The study of diversity-factors has not been carried out heretofore in as much detail as is desirable. These deductions are presented as a tentative contribution to a subject which has many angles and must submit to revision as experience and more careful observation may demand, and they should in no wise be considered as the last words on the subject, as parts of them have been necessarily drawn from sources that could not be thoroughly verified. It is believed, however, that, as a whole, they are sufficiently near the facts to form the basis of intelligent discussion.

DISCUSSION.

Mr. W. B. Jackson, M. W. S. E.: This subject of diversity-factor has been handled by Mr. Gear in an unusually interesting manner. It is difficult to conceive that the realization of the importance of the diversity-factor in the electric-lighting and power business has been of very recent years. Time may be passing more rapidly than I think, but my impression is that only two or three years ago we did not even have a name for diversity-factor, and that the average plant-manager did not realize, in the least, that this diversity-factor of which we have heard this evening was one of the potent factors that made it possible for the central station to compete successfully with the ordinary isolated plant. The fact is that the improved diversity-factor is one of the important elements in favor of the large central station, and it has been a pleasure to hear this question presented so well by the author, because he is engrossed in just such questions as this, and what he tells us regarding diversity-factor is authentic. A broad appreciation of the importance of such problems as have been presented tonight has undoubtedly been an important factor in making the Commonwealth Edison Co. the greatest electric-light and power company—I think I can truly say—in the world. One of the valuable features of Mr. Gear's paper is that his deductions are so drawn that they are of quite general application when appropriately modified to accord with changed conditions.

Mr. W. L. Abbott, M. W. S. E.: The question of diversity-factor and its ramifications through the whole subject of carrying as much business as possible with the least equipment is a fundamental and vital one with the designers and operators of electric lighting central stations. About two-thirds of the expense of operating a central station, counting in fixed charges, administrating and all, is for items which can only be reduced in relative volume by making the equipment carry a greater average load. They are not dependent upon ordinary operating-expenses. Therefore, while the questions of pay-roll, fuel, and other such items are always prominently before us, there are other insidious expenses working with the persistence of interest and taxes which are eating up the earnings of the company unless the equipment can also be made to work day and night. The diversity-factor as applied to residence-lighting, where one householder does not leave his lights burning while he goes to visit a neighbor who has an illumination in honor of his guest, is one feature of this question. The fact that the householder is not at home using his lights, and is not at the factory using his power while he is riding home on the street-car, is another feature, and the more places that the consumer can be touched,—in his home, on the street-car, in the factory or office, in the restaurant at noon, printing his paper at night, and so on,—the greater the profit will be on the investment.

It occasionally happens that while the customer is in his office using light in the latter part of the afternoon when it gets dark early, his family at home are turning on the lights. That is the one time of the year when we cannot split up on the customer and distribute time evenly over the 24 hours. We wish we could, however, and that he would issue a rule at home that no lights should be turned on until he gets there, or until he has put the lights out in his office and finished his street-car ride.

About one-fourth of the generating-station investment is for the purpose of supplying that service during a few hours of the day and a few days of the year when the lights are burning both in the home and in the downtown business-place. The power which we have to generate for this purpose and which is sold for, we will say, 10c per kw. hr., costs the company not less than $1.00 per kw. hr., and if there was some way of applying the diversity-factor to this character of load,—cutting it off at that time, chucking it into the inverted peak which occurs at noon, using it after midnight, burning it up in the summer-time, using it on Sundays, or even giving it to the competing company, any way to get rid of it from the time and place where it occurs,—there would be a great saving. That, however, is a feature which pursues the central station wherever it is located—in this city or in any other city, in this country or in any other country. They all have that piling up of two classes of load at about five o'clock on the afternoons of long winter days.

I have discovered a way in which we can partially obviate this difficulty, although the method is not yet patented. A degree of longitude at the equator measures about 70 miles; in this latitude a degree of longitude measures about 50 miles; there are four minutes' difference of time for each degree of longitude; therefore for every 50 miles east or west we pass four minutes of time. I propose to establish a station at some convenient place, midway between two large centers of population about 400 miles apart. This will give transmission lines reaching 200 miles each way. By this means I will be able to supply both cities whose lighting-peaks will come half an hour apart, and I will be able to carry about 25% more load on my generating-plant than I could if my customers were all in one city. All that I am looking for now are convenient locations to put two cities and a good place to build the power house.

Mr. H. Almert, M. W. S. E.: I do not know where the term diversity-factor originated, but I am inclined to think that it originated with the Commonwealth Edison Co. In that organization I really believe they have the greatest diversity-factor of any organization in the electric-light and power business in the world.

At the Atlantic City meeting of the National Electric Light Association, Mr. Insul, President of the Commonwealth Edison Co., devoted a great deal of time and energy toward the education of the managers of the small central stations. It is really appalling to find what poor diversity-factor and what poor load-factor some of the small central stations have; this might be materially improved by intelligent management.

I had occasion recently to examine some properties in the southwest, where there was a very great diversity-factor as far as classes of service is concerned. In one city there are two municipal water-works, two private water-companies, three electric-light companies, two street-railway companies, one artificial-gas company, one natural-gas company; there they have too good a diversity-factor from the number of sources of service. In that town two of these stations supply seven different classes of electric service, and one of them furnishes five different classes of electric service, each from duplicate lines in the same territory. When one stops to consider the enormous investments of all these companies per kilowatt-demand, Mr. Gear's figures look small. Their investment per kilowatt will run up to something like three times the lefthand column of Mr. Gear's table. They have a combined load-factor of about 9.2%. There is room for a great deal of missionary work in that district.

I think Mr. Gear's paper, if carefully studied and carried into practice, would show increased earnings on public utilities that would have a very beneficial effect on that class of securities, and therefore I think it should have a wide circulation.

Mr. S. Morgan Bushnell, M. W. S. E.: The kilowatts shown in the bottom line of Table 2 are not clear to me. Does Mr.

Gear mean kilowatts connected, or kilowatts of maximum demand, or kilowatts of station capacity?

Mr. Almert: I would like to have Mr. Gear explain how that maximum is determined,—whether it is a momentary maximum, or a momentary maximum for the year?

Prof. P. B. Woodworth, M. W. S. E.: In Table 2, as shown, I suppose the figures in the top line are based on a constant value of generating capacity, since it appears that the 30% of $500.00 in the column headed "dense residence" is the same as 60% of $250.00 in the column headed "large users." I do not quite understand why there is such a difference between the cost of transformers for scattered residence distribution and large users. The cost of transformers for scattered users is about $16.00 per kw., while for large users it is $7.50 per kw.

Mr. A. Bement, M. W. S. E.: Two things occur to me. One is that electrical people are very scientific in their business,—much more so than people in other occupations. There is probably no business of any size or character in which conditions are so fully analyzed as they are in the electrical business; this, I think, has done a great deal in putting the electrical business where it is, and a lack of analysis of the essentials in many other lines of business accounts for their less successful development.

Electrical people are prompt to invent terms by which they may express their meanings and convey their ideas to others, and thus be able to make each other understand what is being talked about. Lack of proper terms often causes confusion in stating a problem and conveying to others the meaning desired, with the result that people beat about the bush and say things that are taken to mean something else. The invention of the terms or expressions that come along so promptly and frequently in the electrical business is of great assistance to the prompt solution and the ready realization of ideas as they develop.

Mr. G. H. Lukes, M. W. S. E. (Chairman): Mr. Gear has shown in the left-hand column the total investment per kilowatt for scattered residence districts, and he has explained that in the fringe around a large city, and in the city itself, business often has to be carried at a loss. As one gets further out, the problem of operating the company with financial success becomes exceedingly difficult, and that explains why there must necessarily be a difference in rates. I presume that the figure of $820.00 per kw. would go up as one goes out from the center of the city. Necessarily, as the diversity-factor cannot be greatly improved, the rates for that class of business must be higher,—must be kept above city rates.

Mr. F. F. Fowle: One of the things that occurs to me as notable is the system of rates which has brought about the large diversity of demand which Mr. Gear has so clearly shown, and which, broadly speaking, is a sliding-scale system of charges based upon the theory of charging in proportion to the quantity used. This contrasts with the early days when the flat-rate system was in vogue, and it is notable that there has been a very recent tendency in some cases to go back to a flat-rate system of charging in connection with Tungsten lighting. But it seems to me that this diversity of demand has made possible the very great commercial development now enjoyed, because of the fact that so many different kinds of business can be taken care of, particularly in the residence sections, over a given set of feeders and transformers. If that were not so—if no such diversity-factor were present—we would find it impossible, probably, to give service at the present rates or at rates anywhere nearly as low. If we should go back to any extent to a general flat-rate system, it seems to me it would have a very profound effect upon the diversity-factor, and in turn upon rates.

I recall some figures from an electric property in a city of about 16,000 population. It had a connected-load of approximately 1400 kw., and the maximum winter-peak was about 600 kw. The summer-peak I think ran considerably less than 400. I was interested in Mr. Gear's remark, too, that diversity-factors probably are not the same in any two properties. In the city of which I speak there was a notable difference in the daily peak—the instantaneous peak—from day to day in any one week. That city had a very large industrial development, and it was notable that the stores were open on the evening of pay-day; there was always a very large load on that day; in fact, it was generally observed that the highest peaks in the week came on the evenings when the stores were open. In those cases it was quite notable that the power-load, which was considerable, produced a very high winter-peak because it overlapped the lighting-load. Those loads became separated in point of time or coincidence in the summer and resulted in a much lower peak.

CLOSURE.

Mr. Gear: The generator-capacity was figured at $150.00 per kw., and the substation capacity at $55.00 per kw. straight through. The other figures—feeders and mains—were made in a more or less approximate way, and for any particular case would have to be figured out individually. The term large user refers to customers of 300 to 500 kw.; in fact, those particular figures were made up for a 300 kw. customer with 100 kw. units, which cost about $7.50 per kw. On the scattered power a little higher cost per unit of transformer-capacity would apply,—that is, somewhere about $8.00 to $10.00 per kw.,—because it would be in smaller units; but there is a larger diversity-factor between the transformers and the feeders in scattered power, which makes the amount of transformer-capacity for a given amount of feeder-load twice as much for that class of business as it is for large users; so that for 5 kw. of feeder-load it takes 10 kw. of transformer-capacity, whereas with the large user the transformer-capacity need be only 25% more. The cost per kilowatt of station-load is therefore higher for the scattered-power load.

The same explanation applies to the meter-cost. The cost of the meter is about $10.00 for a 5-ampere meter having 0.55 kw. capacity, and about $20.00 per kw. if it carries its full load, but when the diversity-factor is applied, it runs up to 34% of $500.00, or $150.00 to $160.00 per kw. That explains the high cost of equipment where the diversity-factor is large.

It might be of interest for you to know that in the outlying districts of Chicago the Commonwealth Edison Company's investment in meters alone is over $100.00 per kw. of station-demand, so that these figures are not merely theoretical,—they have been actually realized.

In regard to the difference of diversities in different plants or different properties, that is one of the reasons why it is difficult to draw final conclusions which are generally applicable to every property. Chicago is such a large city that we have illustrations of that fact right within our own city. The requirements of the West Side are entirely different from those of the residence district on the North Side, and the requirements of the South Side are still different, so that the diversity-factors in those sections of the city are different. The proportion of power and commercial-lighting on the West Side is high as compared with the residence-lighting, while on the South Side it is very low compared with the residence-load. On the North Side there is considerable power in the district south of Fullerton Avenue, and a very heavy residence-load north of Diversey Boulevard. On this account it has been possible to get a good deal of information about different classes of load.

The kilowatts shown in the bottom line in Table 2—referred to by Mr. Bushnell—are the maximum kilowatts at the generating-station. That is, for each kilowatt of maximum demand on the generating-station, the investment for the entire system would be $820.00, as shown at the foot of the second column.

On a mixed lighting and power system—as in any large generating-system—the load comes up and goes down gradually. The actual maximum usually lasts at least ten minutes, and momentary swings are not considered.

DEPRECIATION AND RESERVE FUNDS OF ELECTRICAL PROPERTIES.

WILLIAM B. JACKSON, M. W. S. E.

Presented at a joint meeting, W. S. E. and A. I. E. E., April 27, 1910.

Every company operating an electric light and power property, a street railway property, or a telephone property, or contemplating entering into any such field of activity, must take into account certain expenses that cannot be appropriately included in the day by day operating and office costs or in the current maintenance expenses of the property, if its accounts are to show in full the actual cost of performing the services required.

I refer to the sums of money that must be set aside to cover depreciation replacements and to provide a reserve fund to care for extraordinary costs as hereafter explained.

The term *depreciation* as here used may be divided into two parts:

1. Decrepitude—Which covers the gradual wearing out of the apparatus from the effects of use and of age, which cannot be overcome by current repairs, and which results eventually in ending the operative life of the apparatus.
2. Obsolescence—Which takes into account the reduction in the useful life of apparatus, on account of advances in the art whereby otherwise operative apparatus is made uneconomical for further use.

The term *reserve fund,* as here used, may also be divided into two parts:

1. Required Reconstruction—Which takes into account reconstruction costs made necessary by municipal or other legislative requirements.
2. Special Insurance—To cover expenses that cannot be forecast with any degree of certainty, caused by extraordinary occurrences such as unusual storms, explosions, great conflagrations, acts of strikers, etc.

In considering *depreciation* it is well to clearly separate in one's mind the annual depreciation of the plant as an average whole and that of the component parts making up the plant. To obtain the true amount of the annual depreciation in the value of any property, it is necessary to estimate a sum of money which represents the yearly depreciation of each of the component parts of the plant, and the aggregate of these sums of money for all parts of the installation gives the annual depreciation for the plant. This may be converted into a percentage on the total value of the installation which is subject to depreciation. Any method of arriving at the amount of annual depreciation that does not take into account the individual depreciations of the component parts of a plant, must be an approximation at best, even though it may be based upon results obtained in a correct manner for other similar plants, and it may be very far from accurate.

This division of a plant into its component parts for purposes of determining its annual depreciation is usually a simple matter. It requires that each of the component parts shall be such that when it has reached the end of its useful life the part in its entirety will be discarded, and that it shall be possible to intelligently determine its probable salvage value as a whole. If these requirements are not fulfilled the part should be divided until they are.

If we consider the overhead distribution lines of an alternating current electric light plant, the lines may be divided into the following parts: bare wire, weatherproof wire, rubber covered wire, transformers, lightning arresters, insulators, and poles and cross arms with their hardware; and in some cases there may be further divisions. The poles and cross arms with their hardware can usually be considered together as one part, as cross arms and hardware generally outlast the poles but seldom are used again when their corresponding poles are discarded, so that a pole and its fittings may be considered as having useful lives of equal length. It will be seen how impossible it would be to determine a fair amount for the depreciation of poles and wires without thus analyzing the aggregate, owing to the widely differing useful lives of the two kinds of plants and the great difference in the proportions of their salvage values. Or again, consider electric railway track; there are the ties with short life and no salvage; there are the rails with medium life and good salvage; there are the frogs and switches with short life and low salvage; and there is the electrical bonding which may be considered as having the same life as the rails and to have medium salvage. It would be impossible to determine a fair annual depreciation for track considering all of these parts together, but it is possible to obtain the fair average depreciation by taking the aggregate of the amounts found by considering the several parts individually.

The total amount of depreciation to be annually charged against any part of the installation should be equal to the first cost of the part installed ready for service plus the cost of removal, less any salvage obtainable for the part when discarded, divided by the years of probable life of the part.

The estimation of what is the fair useful life for any part of a plant presupposes a thorough knowledge of the nature of the service demanded of the part, a broad acquaintance with the general experience respecting like kinds of plant, a studied survey of the probable effect of local conditions upon the useful life, and a keen knowledge of the past and present progress of the art for the purpose of making an intelligent forecast of the rate of depreciation caused by approaching obsolescence. A fair determination of the useful life is thus based upon several independent variables, and the result must be reached by judgment after duly applying what seems to be due weight to each of the factors involved.

In estimating the fair salvage value to be assigned to any part of an installation, it is often possible to fix it by some relation to the actual junk value of the materials comprising the part. For instance, the salvage value of a lead-covered paper insulated cable that has finished its useful life will be substantially the residue of the junk value of the lead melted off, and of the copper with the paper burned off after the cost of withdrawing the cable from its place of service and preparing the junk has been deducted, though sometimes cable rejected for use in one kind of service may be used in another, in which case its value when discarded from its original use may be the value of cable that would ordinarily be used in the second service, assuming good engineering judgment in the construction and operation of the property. The matter is not so simple with buildings and machinery. With the former it will frequently be found that the cost of removal will equal the junk value, and the salvage value is therefore zero; while with the latter the price that can probably be obtained from a second-hand dealer for the machinery in place may sometimes be considered as the salvage value, and in other cases the salvage value is the price that can be obtained from an old metal or junk dealer for the machinery in place.

The factor of obsolescence entering into the question of useful life of plant, whether of buildings, machinery, or other plant, is a disturbing one. This has the effect of reducing the estimated useful life of many parts of most plants below that which would be indicated by the ravages of decrepitude, and it likewise affects the probable salvage. Where the factor of obsolescence is estimated as likely to terminate the useful life of a part before decrepitude would be likely to cause its rejection, the former factor must determine the useful life. Consequently, the factor of obsolescence may be the determining factor in fixing the length of the useful life of some parts of a plant, and decrepitude may be the determining factor in fixing the length of useful life of other parts. In other cases these two factors may jointly influence the length of life. The factor of obsolescence has been an exceedingly important one in the several kinds of properties under consideration, and especially so in connection with all kinds of switchboards and other controlling apparatus. But its effect is very apparent, even when considering what we think of as the most stable parts of an electric generating plant, though revolutionary effects are not so apparent today as they have been in the past. Let us consider a large high grade engine-generator set for alternating currents. Few of us would be willing to place at less than fifty years the period during which such a machine should be physically capable of doing, under good care and management, the particular work for which it was designed; but no conservative engineer would allow, when estimating depreciation, that such a machine will have, in ordinary commercial electric service, a useful life of fifty years, because advances of the art would inevitably affect its usefulness. In consideration of the great changes that have taken place in the past in apparatus for the generation and distribution of electric power, and the probable changes that will take place in the future, such a piece of apparatus cannot appropriately be allowed an estimated useful life of over twenty to thirty years. Local conditions also may influence to a considerable degree the length of the useful life that may be allowed.

Most public service companies are forced to make large expenditures by ordinances of municipalities or by other legislative action. These are required changes, such as changes from overhead construction to underground construction, relocation of distribution lines on account of new street surveys, changes from wooden poles to iron or steel poles, changes in track construction owing to paving of streets, etc. The costs of such changes up to the value of the original construction should not be made an addition on capital investment and they cannot appropriately be considered as a part of current maintenance, but they should be provided for by a *required reconstruction* fund. An adequate estimate of a suitable yearly contribution, on account of required reconstruction, can only be accomplished after a careful study of what expenditures have been made in the past on account of required changes in the plant under consideration, accompanied by a study of the district served by the plant with the view of forming a judgment of what requirements are likely to be imposed in the future. In the case of changes from overhead to underground line construction that are likely to be required, it is sometimes possible to make quite definite estimates of the cost of such changes for many years to come by a study of the character and probable rate of development of the territory covered by the company's lines, from which an estimate can be made as to what will normally become underground territory year by year. And in some cases a regular schedule of such changes is determined by city ordinances.

The question of what annual charge should be made on account of *special insurance* is also difficult to solve with exactness, but it is one of which sight should not be lost. The ordinary maintenance expenses should not be expected to include such costs as those occasioned by the destruction of a power house roof by a wind storm, the annihilation of a boiler-room by a boiler explosion, the razing of a pole line by sleet and storm, etc. It is, therefore, appropriate that an annual amount be laid aside for each part of the plant, except, of course, land, to create a fund to remedy such damages which come once in a while to every plant. The element of chance must enter very largely here, but chance is not such a fickle factor in operations when its effects are distributed amongst many parts of a plant.

These factors of *required reconstruction* and of *special insurance,* which I have considered under the heading *reserve fund,* are quite different in their characteristics from depreciation, but a plant will just as surely get into the breakers if its reserve fund, or some equivalent to meet these expenses, is not kept in good shape as when no provision is made to take care of depreciation.

If replacements are taken care of by capital account, a property becomes burdened by an imaginary capital investment in physical property which is almost sure to be a serious handicap when the company desires to reduce rates or make improvements. Where replacements are permitted to be taken care of by capital account, the capital account becomes something like the wallpaper in a room (to use a homely comparison) which has been put on layer upon layer, the old not having been removed when the room is newly papered. The papering is not worth more than the last effective layer, and in fact the lower layers sometimes prove the destruction of the whole, and so it may be with an inflated capital account.

By capitalizing replacement costs, the burden of carrying these costs is thrown upon the future without limit of time in cases of unlimited franchises, when this burden should have been borne by the past, except during the period in which a company is still in process of building up its business to a remunerative one.

Most plant managers have not yet come to a full appreciation of the dire straits a plant must come to sooner or later if the depreciation appropriations or their equivalent are not systematically and intelligently attended to. We may consider, for example, a property having a large investment in pole lines. This may amount to as much as 10 per cent of the value of the plant. For the first ten years comparatively few replacements of poles will be required, but during the next two years most of the poles may have to be replaced. Thus an average amount of money equal to almost 5 per cent of the plant investment may need to be expended each of these years for pole replacements alone, and other parts of the plant are surely and irrevocably coming to the same condition. Thus, if there has not been due regard given to a depreciation fund, or the plant is not extraordinarily prosperous, great difficulty will be encountered in obtaining the necessary money for replacements when their need begins to be acutely felt.

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A third division is sometimes made in depreciation, called *inadequacy*. This factor covers costs which are occasioned by the necessity of discarding otherwise serviceable plants on account of growth of business. For example, if an electric plant is operating with three small dynamos, and it is found necessary to increase its capacity, it may be best to displace one small dynamo by a larger one, even though the small dynamo may be far short of having operated during its entire useful life, estimated from the standpoint of depreciation. The fund accumulated on account of depreciation for this dynamo, plus the salvage, would likely not cover the loss occasioned by discarding the apparatus at that time. This difference might be made up by a contribution to the depreciation fund on account of inadequacy. This factor should be of small importance in a plant planned and operated with excellent engineering judgment, and it is so closely allied to obsolescence that it does not seem necessary to add a third division to depreciation. It may be properly considered as a part of obsolescence wherever it enters as an appreciable factor in any consideration of depreciation.

The expenses that are considered in the foregoing pages are as real as the pay-roll and other daily operating expenses of a plant, but the ravages of depreciation frequently do not show to a noticeable degree until several years after the beginning of the operation of a plant, and there are also likely to be long periods during which it is unnecessary to make much, if any, outlay on account of required reconstruction and special insurance. For these reasons there is serious danger of overlooking the importance of these expenses in promoting a new enterprise, or in the early days of the operation of a public service company. But if the earnings of a company, after it has become well settled in its business, are not sufficient to cover a fair appropriation annually to the depreciation and reserve funds, as well as to cover the regular operating expenses and a reasonable return on the investment, that company is one that conservative investors should shun. If the conservatively estimated earnings of a new project do not show that they will provide such returns, it should not be considered an attractive project.

Having considered the general question of depreciation and reserve funds, let us now consider how the principles involved should be applied.

Few kinds of apparatus depreciate in value by equal yearly increments, but nevertheless the final effect of decrepitude or obsolescence is to eventually wipe out of the true assets of the company the value of the part less the amount saved by salvage. Such being the case, it will be readily seen that as a piece of apparatus having a useful life of n years, for example, will be in service just n years, each year of service will reduce its serviceableness to the owner one nth part. Its depreciation should, therefore, be based upon equal yearly increments of one *n*th, in determining the annual contribution that should be made toward the depreciation fund.

Therefore an annual contribution to the depreciation fund should be made such that in *n* years it will accumulate an amount equal to the first cost of the part installed ready for service minus the net salvage, net salvage being defined as the junk value less the cost of removing the part and preparing it for sale, that is, as the net sum recovered. But the annual contributions should draw interest at the usual trust rate for the state in which the plant is located, and the annual contribution to the depreciation account is, therefore, less than one *n*th of the first cost of the part. Thus, if the trust rate is 4% and *n* is 10 years, the actual percentage of the cost that need be set aside annually would be 8.33% of the first value of the part minus estimated net salvage. In this way the annual contribution to the depreciation fund for each part, or group of parts having the same useful life, may be determined, taking into due account the differences in life and salvage of different parts, and the sum of these several amounts gives the annual contribution to the depreciation fund for the entire plant. With this amount known, the proportion which the annual contribution to the depreciation fund has to the total cost of the plant subject to depreciation is at once available, and the percentage of annual depreciation is known.

This statement may be qualified to a certain extent by the fact that every plant will take some time to obtain a paying business, and that during this period of upbuilding it is not expected that the earnings should cover a depreciation fund. Such being the case the annual appropriation to the depreciation fund would be omitted during this period (which should not be long) and correspondingly increased for the later years of operation.

In case of reconstruction and special insurance, the average annual amount of expenditure that is likely to occur must be determined as closely as possible in the manner already described, but here no trust interest can be considered, for, while at times the fund may show an accumulation, at other times it may be negative, so that interest received at times of accumulation may be considered as offsetting interest paid during times of borrowing.

The accumulation of these funds is for specific purposes and the money should be used only for those purposes. Also, those purposes should be supported solely from these funds. Thus, when property must be replaced on account of its depreciation, the cost of doing this (less salvage on the discarded plant) should be defrayed out of the depreciation fund, and when an underground line must be substituted for a useful overhead pole line, on account of municipal legislation, only the difference between the first costs of the underground and overhead lines should become a capital charge, and the remainder of the expenditure (less salvage) should come from the accumulated funds. It is obvious that the depreciation fund will accumulate in the earlier years after a plant has been established, because the replacements during the earlier years will be few; but after a plant is fifteen or twenty years old, the expenditures for replacements and the contributions to the funds will somewhat nearly balance when averaged over several year intervals. In all but the very largest and most comprehensive plants, the expenditures for replacements and required reconstruction will vary greatly from year to year, but the amount contributed to the fund each year should follow the computed average figure; and the sum maintained in the funds may therefore vary.

Sometimes depreciation funds are put into new plant instead of into accumulated funds. There is some question as to the advisability of this. Unless the books of a company are kept with extraordinary care, or the plant represented by the depreciation fund is kept distinct from the remainder, it is difficult to keep track of what plant represents capital investment and what represents depreciation. This difficulty is magnified, as the plant representing depreciation itself depreciates, thus introducing an additional factor that must be taken care of in the bookkeeping, and eventually the concern is likely to lose the enviable situation of having its books show the actual facts regarding its property.

It may be said that an old plant worked down to its ultimate operating condition will have an annual expenditure for replacements which remains approximately uniform, so why permit the depreciation fund to lie as a trust fund when it might be actively used in additional plant? If the depreciation fund is put into plant, the company is likely to lose its ability to show the relation of its physical property to its capital investment, and it cannot then show a true relation between earnings and the physical value of its plant. The fact cannot be ignored that the people of this country today expect public service companies to be in a position to show that their service is satisfactory and supplied at a reasonable cost, and it, therefore, seems necessary that such companies should be able to know their actual investment in property which represents capital invested.

The coming of public service commissions, having power to regulate the rates of public service companies, has raised the question whether the depreciation of a plant should have an influence upon the earning power of the company. It seems patent that a company should be permitted to earn a fair return on a full, reasonable, unimpaired capitalization regardless of depreciation, so long as it supplies equally good service. This question would not seem to me to be open to doubt were it not sometimes a subject of serious discussion, and were it not that some respected publicists seem to hold that the net earning power of a public service company should be less after its plant has been subject to depreciation than when brand new, even if it gives equally good service and the stockholders have received back no part of their invested principal, but only fair returns in interest.

With a properly conducted property the fact that the property has suffered depreciation, which is unavoidable in any electric plant, should not have the effect of injuring the quality of its service or of impairing its capital, which would be the case if its recognized earning capacity were expected to decline proportionally with the increase of its depreciation fund.

If a fair figure has been estimated for the annual contribution to the depreciation fund, this fund will always carry sufficient money to make replacements when required, and as the income from the depreciation fund is used to help build the fund, the owners of the property will not receive returns on their money twice. The investment in the property does not diminish as the plant depreciates, and I do not understand that any one claims that an amount equal to the depreciation may appropriately be distributed to the security holders of the company and thereby reduce the capital outlay in physical property. If the security holders are permitted to receive interest and dividends based upon a fair return on the investment in their property during the first years of its operation, I am unable to see how this basis may be fairly changed during later years, so far as investment is concerned, after the plant has depreciated, as the investment has remained unchanged.

There is another phase of depreciation I would like to touch upon before closing.

The tendency of today is to make sweeping changes in plant and methods, to permit of less expensive or of improved service. On this account many excellent plants in good operating condition are shut down and the requisite power received from other sources. A company cannot well charge off of its capital account the value of such plants which may be comparatively new when they are put out of commission. In fact I have in mind a plant of 1,000 kw. capacity, which is of modern design with steam turbine-generators not over two years old, which with several other plants is being shut down owing to the possibility of obtaining power from another source at less cost than it can be produced in these plants. The question is, what should be done regarding the capital value of such plants? Unless it is necessary to retain the plants in reserve, I believe they should be dismantled and the capital of the company reduced by the amount received from the sale of discarded machinery and other property. Then the difference between the amount received from their sale and their actual capital value to the company may still be continued as a true asset of the company, and that value be gradually charged off at the normal depreciation rate of the plants discarded, the capital of the company being reduced each year by actual liquidation of that amount. In other words, the situation is one wherein the regular depreciation appropriation is made on account of the property until the full cost of the discarded property is returned to the security holders. After this no further appropriation should be made on account of depreciation of the property concerned, as no replacements would have been made on the property, and consequently it would have been depreciated out of existence. The economies derivable from abandoning the discarded machinery should be sufficient to extinguish in this way the capital value of the abandoned plants, or else the transaction is not an advisable one.

In conclusion I will say that, where electrical properties have been failures in the past, a goodly proportion of the failures may be traced to lack of provision for depreciation expenses and for extraordinary expenses. The reserve fund, besides covering such extraordinary expenses as are mentioned in the foregoing discussion, must be sufficient to care for losses occasioned by any recession of income which may come in the train of the physical results of the extraordinary occurrences discussed. The proper organization of a depreciation fund in conjunction with the reserve fund will also fortify a company against difficulties on account of reduced net earnings during lean years, which every company must expect, and which lean years will be offset by good years.

All of you will appreciate that it is impossible to figure the expenses considered in the foregoing to a high degree of exactness, but they may be figured logically and intelligently, and it may be said that a company which follows the principles here laid down regarding depreciation and reserve funds is likely to travel along an untroubled path so long as its field of operations provides sufficient earnings to warrant the company's existence.

Discussion.

Mr. J. G. Wray, M. W. S. E. (Chairman): We are greatly indebted to Mr. Jackson for this very interesting and instructive paper. The public, many publicists of note, and, indeed, the managers of some of our public service corporations and of other corporations, have failed in the past and even today fail to realize the importance of this subject. The subject of depreciation has been driven home to public service corporations, particularly during the last few years, because of the interest taken in the operation of the public service concerns by the public, by state commissions, and by municipal authorities. The idea of piling up a large fund, which in a big public service corporation may run up into the millions, strikes one who has not made a study of this subject as merely another way of getting an undue amount of money from the public.

The management of corporations, and in particular of public service corporations, has perforce to be done on a more scientific basis than in the past. The treatment of depreciation, as I say, is a subject of the last three or four years with most companies, and in fact of even more recent consideration by many of them. I have in mind that the president of one of the oldest and largest public service corporations said not many weeks ago that a depreciation fund was quite unnecessary, as the maintenance account served to take care of both upkeep and replacement.

I am sure there are a great many here with experience who will disagree with that gentleman.

Mr. C. N. Duffy, Comptroller, Milwaukee Electric Railway and Light Co.: I am a little embarrassed, talking before all these engineers, because I am not one of them. I am nothing but an S. C. A. (a So-Called Accountant). This is my apology for talking on depreciation. However, the chairman has made some reference to the Milwaukee Company, and without taking too much of your time, I will state that in 1896 the city of Milwaukee sought, by an action in the courts, to reduce the fare from five cents to four cents. The case came up before Judge Seaman in the United States District Court. The cost of the property was proved to be $8,885,000, tangible and intangible. Mr. William J. Clark, of the General Electric Company, made an inventory and presented it in evidence, showing that the physical cost of the $8,885,000 was $5,200,000. The remainder of the cost sum was the *buying* of the situation. This may be digressing from depreciation, but it is of interest in our case in Milwaukee. The $5,200,000 invested in physical value was of no value without the buying of the situation; the situation was of no value without the investment of the $5,200,000 in the property. The situation bought was the buying of several properties and merging them into one, and although in many instances they represented only a franchise and two streaks of rust, they had to be bought and the person that was selling had the naming of the price. In the case referred to, as may be familiar to some of you, the language of Judge Seaman in making the decision was that it was quite clear to his mind that there had been at least $7,000,000 in cash put into the property; that there had been at least $5,000,000 of that $7,000,000 put into physical property, and that on the testimony of witness Beggs (Mr. Beggs at that time was associated with the company only in an advisory capacity; he afterwards became and is now its president and general manager) it was very clear to his mind that if depreciation had been recognized and provided for in the accounts of the company, the annual return on the investment would be too small to permit of any thought of reducing the fare. In 1906, exactly ten years afterwards, we were met with another issue. The city of Milwaukee sought to reduce the fare from four cents to three cents. I might say, in passing, that subsequent to 1896 (in 1899) there was an ordinance passed giving the company the right to operate for thirty-five (35) years, from January 2, 1900, on condition that we would make a four-cent ticket fare, twenty-five tickets for a dollar, or six tickets for a quarter. In 1906, notwithstanding this ordinance, which was a plain contract between the City and the Company, the City sought to reduce the fare from four to three cents. We took up the question of the defense of the case on the lines of this paper, as to depreciation, and I want to give expression here to the value of many of the points which Mr. Jackson has brought out in his paper, one of them in particular, that a depreciated property does not represent a diminished investment. There was a physical examination of the property by the Wisconsin Railroad Commission. I believe that Professor Pence has enlightened this Society as to how it was made. The books of the company for ten years were examined for the City by Barrow, Wade, Guthrie & Co., and upon that evidence they sought to proceed against our company in the matter of the reduction of the fare. The case was tried before the Railroad Commission of Wisconsin. (Tried is hardly the proper word, hearing I should have said). We had a hearing before the Railroad Commission of Wisconsin which occupied some seven or eight weeks, and our contention was that the $5,200,000 of physical property which had been proved in 1896 in the courts should be taken as being worth at least 80% of new cost; 80% represented about the proportion of the existing value to the cost new as made for the entire property as of December 31, 1906, by Professor Pence. We took this value as $4,000,000, and to that we added only the cost of physical property without any discount on bonds, without any promoter's profit, without any interest during construction, and with absolutely nothing of an intangible nature. It was the cost of the physical property as produced under work orders in our own organization. This cost made a sum in round numbers of $14,000,000. The position we took was that we were entitled, after operating expenses, taxes, and depreciation had been taken care of, to a fair return on that $14,000,000. We did not stand on our legal rights. We did not claim anything for intangible investment or overhead charges or bond discount. We took this as a basis, feeling that it would be better to take the minimum basis and then go up, if necessary, rather than to start high and drop down. This physical property in round numbers was valued on the basis of existing conditions by Professor Pence and his staff at $7,000,000. Mr. Beggs, president and general manager of our company, beginning January 1, 1897, arbitrarily appropriated out of the earnings of the company—without any thought of the lives of the different classes of property, the type of the apparatus, their use or anything of that kind, or the investment in any sinking fund—10% of the earnings as a depreciation fund to take care of extraordinary replacements and renewals, as distinct from current ordinary replacements and renewals which were charged into operating expenses as maintenance. Now, from January 1, 1897, taking the value of the physical property at $4,000,000, plus in round numbers about $10,000,000 added physical property, in ten years about $7,000,000 of that property had disappeared, according to the valuation of Professor Pence, which valuation none of us ever questioned. We had every confidence in Professor Pence's honesty and ability. What does this mean, or what did it mean? It meant that the company had sustained a loss, not taken on its books, in round numbers of $3,600,000. It meant that the 10% of the gross earnings set aside was only equivalent to about half of the amount that should have been set aside.

I make this statement, partly in response to the statement of your chairman, that there are some people who claim that a depreciation fund is not required. I have heard this debated in meetings of the American Street & Interurban Railway Association. I have heard managers of some of the largest properties in this country assert that the maintenance took care of depreciation, so that there was no depreciation. But that has not been our experience. We do not want to argue the case. It is unnecessary to argue it. Consider the facts.

Now with regard to what Mr. Jackson said, that he was giving expression to his own ideas in a general way as to what constituted the main questions regarding depreciation. I think that he is to be congratulated that he has presented a paper along those lines. There are some points which do not quite appeal to me as practical propositions. For instance, this question of building up the depreciation fund on the sinking fund plan. Now as I understand Mr. Jackson, he wants to give expression to the necessity of recognizing the figuring of depreciation on that basis, but does not intend to give the impression that it is absolutely necessary to invest money in a sinking fund in order to accomplish the results which he says must be, and which we know have to be, accomplished. What I mean is this. I do not believe, as a practical question, that an electric property, be it railway or lighting, can absolutely set aside, year by year, the exact amount proportionately and invest it, in order to work out the depreciation fund on the assumed basis of the interest increment being added to the amounts set aside. There are many reasons why that cannot be done. In the first place, there is the question of lean years, particularly when the property first begins operations; the first five years more than likely will show deficits rather than surpluses. Then comes the question whether or not the money can be invested—assuming that it has been set aside—and that it can be invested in a sinking fund that will yield the amount required and that the withdrawals from the fund will be in proportion to the way it has been built up.

To illustrate, take the Chicago City Railway Co., or the Chicago Railways Co., on the North and West Sides. Assume that the Board of Supervising Engineers, after careful investigation and consideration of all the factors, determines that the life of a given number of cars—100 cars, for instance—would be (we will say for the purpose of illustration) twenty years. That does not mean that all of the cars will last twenty years. It means some of them will last more and some of them less. Now, then, one must have a flexible fund or he must have his fund in such shape that if it is necessary to replace some of those cars at the end of the fifteenth or the sixteenth or the seventeenth year, or if they run over to the twenty-fifth year, he can take care of them. That is the practical question.

As a matter of fact, The Milwaukee Electric Railway and Light Co. has not an invested depreciation fund. The company built up a fire insurance fund, an injuries and damages fund, and a security deposit fund; these three funds are invested funds and the interest on the investments are added to the funds.

It seems to me that any one who wants to figure out what his depreciation will be must of necessity follow the plan laid down so well by Mr. Jackson in his paper with regard to giving recognition to the interest increment on the depreciation fund. If it is not invested and is used in the business as working-capital, or if it is used for extensions, or whatever may be done with it, it seems to me, as far as true results are concerned, as far as correct accounting is concerned, in the question of rates and service, so far as the relation of the company to the public is concerned, the public must be given the benefit of the increment of that interest. It does not make any difference whether it is invested in a so-called sinking fund or trust fund or not. But there are ways of taking care of this proposition. As a matter of fact during the first five years of the life of an ordinary property one may not set aside a quarter or a half of what would be the annual apportioned amount. That is why it seems to me that the straight-line basis rather than the sinking-fund basis is the preferable as well as the more practical one. In the second five years 50% or 75% of the annual apportioned amounts might be set aside, and in the next ten years one may make up what was lost in the earlier years. There is nothing to prevent this as far as the accounts are concerned. To meet the gentleman who says that interest on the money is being obtained twice, the depreciation fund can be credited with the interest and can be deducted from the income, or in taking the depreciation charge on the books, give credit for the interest against the increasing charge for depreciation in the particular year being dealt with. This has been our position in the hearing before the Railroad Commission in the matter of the three-cent fare.

I might say, in passing, that the most recent and I think the most important decision rendered by the Wisconsin Railroad Commission was given out March 8th, relative to the rates of the Madison Gas & Electric Co. In that decision, among things that are highly important to all of us, even to those of us who are not engineers, the Commission intimates that money is worth 6% as the *cost* of the money, and that in a gas property there should be a profit over and above this 6% of 1½% to 2%, and in the electric-light business of 2% to 2½%, and that that profit must be attained after everything has been taken care of, including depreciation and, as I take it, also casualties and several things alluded to by Mr. Jackson. In their summing up of the case and in their decision as to the rates which they reduced,—or rather, adjusted, they were reduced in some instances but it is more generally an adjustment, as I understand it,—they gave the life of an electric light plant on the average (and I think I ought to correct myself there, because I understand from Mr. Jackson that it ought to be, not the life of the plant, but the average depreciation of the plant that should be considered) at about eighteen years, and of a gas-plant about thirty years. They recite the features of the installment plan for the depreciation reserve fund as compared with the sinking fund plan, and they state that at least a 2% sinking fund must be taken into account for the gas, but nothing for the electric plant.

Mr. Wray: I would like to note, in passing, a reference to one of the points Mr. Duffy makes,—the advantage of a straight-line depreciation over a sinking-fund depreciation,—an advantage which would seem to be necessary in the case of a public service corporation that, like the telephone company, is required, or may be required at a certain period to sell out to the city at its depreciated value. The point is a very important one when we recall that the sinking-fund curve is concave to the base. In other words, one does not accumulate an amount which will equal the investment until the end of the life of the plant—the theoretical life of the plant upon which the depreciation figure is based.

Mr. George Weston, M. W. S. E.: The subject of depreciation has become one of interest to engineers and operators of public utility properties, brought about principally by municipal ownership agitation and the activities of federal, state, and municipal governments in the regulation of rates, fares, and capital securities, requiring a *present value* for properties under consideration.

In addition, the importance of depreciation in its relation to the finances of a company has made its study necessary in order to provide for the payments of renewals out of the earnings of the property.

The paper presented here this evening by Mr. Jackson sets forth, in considerable detail, methods for predetermining depreciation of physical property, which briefly consists of determining a cost new and the salvage value for each component part of the property, the difference between the cost new and the salvage equaling the value of the depreciable part. In order to ascertain the average annual depreciation for each component, the wearing or useful life must be predetermined; these calculations are necessary in order to determine the *present value* of any property or to determine an annual depreciation fund to be set aside to take care of the renewal of each component part at the end of its useful life. The first cost, the salvage value, and the useful life of each component part are questions of fact and can be quite accurately predetermined or estimated, and if the earnings of the properties will permit, it is practicable to establish a reserve fund to take care of renewals.

Mr. Jackson, in his analysis of depreciation, has referred to *obsolescence,* extraordinary expenditures due to changes required by municipal ordinances, etc., and also refers to *special insurance* to cover loss due to destruction of property by wind-storms, explosions, or other extraordinary causes, and recommends that reserve funds be established out of the earnings of the property to provide for these extraordinary expenses. Obsolescence and inadequacy of plant and equipment will occur to a greater or less degree in the property of any public-utility or large manufacturing plant. Loss of property is liable to result from extraordinary causes, and public-utility companies, operating under governmental or municipal franchises or ordinances, may be required to make changes in their plants or equipment on account of its obsolescence, inadequacy, aesthetic or other seemingly necessary reasons. However, all of these extraordinary losses are very difficult to predetermine, and therefore should not be included in the factors to be considered in predetermining the rate of depreciation of property, for use as a basis for establishing annual appropriations to reserve funds.

Factors used in determining depreciation for reserve funds should be confined to those necessary to determine the *wearing value* and the *normal wearing life.* Wearing value is the difference between the cost new and the salvage or scrap value. The normal wearing life is the average length of time in years during which the particular class of cars, buildings, engines, generators, or other property considered, will be serviceable, it being understood that the proper *maintenance repairs* will be made from time to time.

The normal wearing life should not be affected by obsolescence, extraordinary changes, extraordinary accidents, etc., for in case supersedence takes place before the end of normal wearing life, then such proportion of the cost of the new article that has accrued to date in the *renewal fund* to the credit of the article superseded should be paid out of such renewal fund, and the balance of the cost could go to Capital Account, or preferably this balance should be carried as a floating debt to be retired by surplus earnings in the future.

As a question of finance, the establishment of reserve funds, to be maintained out of the earnings of the property, depends upon the relation that the gross income bears to the operating expenses and the fixed charges. The gross income should be such that in addition to meeting operating expenses, depreciation, and fixed charges upon the actual investment, the property should earn a fair return to its operators for skill, hazard, etc., but if the property does not show sufficient earnings to properly take care of all of these, then payments should be made preferably in the following order:

1. Operating expenses.
2. Fixed charges.
3. Depreciation.
4. Dividends.

There are different ways of maintaining reserves to cover depreciation, such as a specific cash fund—or, as it might be termed, a *surplus*—and if a specific fund is desired, a basis for determining the amount to be paid into the fund monthly or annually must be found. This should be such as to provide in the fund, as nearly as practicable, cash (or its equivalent) equal to the amount of depreciation at any time during the normal wearing life of the depreciable part of the property or at the end of the period. There are two general methods used to determine the amount of this periodical payment into a fund; one is called a *straight-line depreciation* basis, which divides the total wearing value into a number of parts equaling the normal wearing life, and these amounts are paid into a fund periodically to maintain the fund without reference to interest; the other method is termed a *sinking-fund curve* basis, referred to by Mr. Jackson, and involves the payment into a fund periodically of certain specific amounts bearing interest at a predetermined rate compounded, which will, at the end of the period of normal wearing life, equal the wearing value, or the payments could be changed in amounts at each period so that together, with the interest compounded, the fund will at any time equal the amount of the depreciation. Mr. Duffy, in his remarks, questioned the practical features of a sinking-fund curve basis, on the ground that he did not believe the rate of interest that could be realized from a sinking fund could be predetermined. I believe it is practical to work out a plan so that a corporation can invest its sinking fund in its own securities, and that by so doing an annual rate of interest can be very closely predetermined. This, however, as stated above, is a financial problem and no hard and fast rules can be laid down covering depreciation; each property, being a problem by itself, must be treated as conditions direct unless the earnings can be made to fluctuate at will. In that event, fixed rules or factors can be determined and the earnings regulated to fit the case.

In the past many public-utility properties have been managed by persons who spent as little money as possible for repairs, made no provisions whatever to provide for depreciation out of the earnings, but paid fixed charges and high dividends, thereby placing a fictitious value upon the stock, capitalizing renewals, and in some instances operating expenses as well. Usually, after setting full sail and heading the ship towards financial rocks, these pirates would sell out and leave the other fellow and the small stockholder to endure the losses. These methods of juggling public-service properties have given the public false impressions about profits in the business, and are largely responsible for the general agitation against public-service corporations in the past. The present operators of such properties should adopt a systematic method of counteracting these erroneous ideas by applying, in the operation of their properties, correct financial principles based upon making the properties a commercial success.

Mr. Wray: The point in Mr. Weston's remarks that depreciation is largely a financial question, referred to by Mr. Duffy, it seems to me is very true. A public service corporation during its earlier life, when perhaps its earnings are not enough to more than pay dividends, and when the demands for new capital to take care of extensions are very great, has got to be able to dispose of its securities to advantage; otherwise it will fail. Naturally it should not be required at that time to set aside money in a depreciation fund. It is very essential to keep up its net earnings and to keep up its dividends, so that its securities, its stock, and perhaps its bonds, can be disposed of to advantage, and extensions provided for. The depreciation fund can wait and be taken care of during the fat years.

Mr. C. N. Ubelacker (of Ford, Bacon & Davis, New York): On the short notice with which I was favored this evening, I can not attempt to make any suitable discussion of Mr. Jackson's very able paper, as it is a large subject. I simply want to present to you a few points that have been questions in my mind on the matter of depreciation and on which I cannot say that I have as yet clearly made up my own mind.

In the first place, the question of how we are going to handle depreciation depends largely on the purpose to which we are going to apply our depreciated value. Are we figuring depreciation for the purpose of making a rate? Are we figuring to know where we are going to come out in our financial arrangements? Or are we simply going along adding some certain per cent. of our gross income to a surplus each year, with the hope that it is going to make good any difficulty that we get into in the future? If we are figuring depreciation for the purpose of making a rate—for the purpose of allowing an amount in addition to operating expenses and fixed charges which must go to make up the expense of giving the service—then we have to consider the term during which the service is going to be given, during which we have a right to give the service or a right to expect that we will be allowed to continue to give the service at the rates fixed. In other words, is our franchise or our charter an unlimited one so that the only question we have to meet is our ability to turn out 100% of service from the apparatus and plant which we have, or is our charter and franchise a limited one, at the termination of which, as your chairman drew attention to, frequently it is necessary to give up the property for its selling value?

In the case of a limited term franchise, of course we must take into account that during the term in which we have the right to give the service we have to provide a depreciation fund sufficient to meet the difference between the original investment and the sum for which we can dispose of the property, but I cannot see that it is anybody's business but the stockholders' whether we give them from time to time certain surplus earnings which eventually will have to come out of their pockets, due to difference in the selling value and the first cost of this property, or whether we pile it up in a fund and eventually return to them the whole of their first investment. Why should we make quite such a strong point of depreciation as long as we realize it is going on, and what we are coming up to in the end and do not try to deceive people and make them believe they are buying 100 cents on the dollar, when they are really buying only 90 cents?

There is another question that has some influence on the way we are going to figure on depreciation. That is, what view are we going to take of the service we are giving? Are we renting service, renting the use of a plant, or are we selling the product? If we are renting the use of a plant, it is the business custom that the plant shall be considered at 100% of its new value as long as it will turn out 100% of service. If you pick up a hackman along the street you do not ask him whether his horse is six years old or nine years old. If it will take you to the station in ten minutes you will pay him just the same in either case. If we are giving the service, we are entitled to 100% of our new value as long as the plant will turn out 100% of service. That being the case, why should we charge supersession on the plant that is still turning out 100% of service? Why should we make elaborate provision for meeting supersession after a definite period when we do not know what that period is going to be? Supersession is a very uncertain thing and not subject to accurate prediction.

Depreciation due to wear and tear Mr. Jackson calls decrepitude. I have always preferred to call it deferred maintenance, because it is really maintenance. We might as well have one term as two.

Supersession, as stated above, is a very uncertain thing to figure out, and to my mind it does not take place until the article is actually taken out of place and superseded by another. It has been very rapid in the past, but the experience in the past, which is the only thing we have to go by, is of little help to us. Supersession takes place less and less rapidly as the art grows older. In other words, our curve of supersession becomes eventually asymptotic. I think some of you will remember an account in a recent *Cassier's* of the third locomotive Stephenson built. It has been in operation ever since (over 80 years) and is still in service. There have probably been a great many repairs and there are not many of the old pieces in it, but supersession has not taken place. So why build up a big fund for supersession, when we do not know when it will occur? Let us go back to the principle that the new apparatus which goes in will earn sufficiently more money, or will operate sufficiently more economically, so that the difference in the receipts or in the expense between that and the piece of apparatus which has been superseded will take care, in its term of use, of the cost of what we have discarded or the working value of the superseded apparatus. Why not let the man that gets the benefit of the improved service of the new apparatus pay for it? Why should we load on to the rate or on to the cost of service from the original apparatus the cost of what is eventually going to be improved service in the future? The man that ought to carry this expense is the man that gets the improved service, and for that reason why not look upon supersession as being taken care of out of the increased economy of the superseding apparatus? These are questions concerning which I have not yet decided myself, and I would like to see if I can get any light on them tonight.

Mr. E. J. Fowler (Statistician, Commonwealth Edison Co.): I suppose that among the electric-lighting companies there are about as many different methods of keeping track of depreciation as there are different kinds of rates. There are a great many companies, of course, that do practically nothing along this line, and there are not many that go into the subject very thoroughly as yet, but to my mind they will all have to go into it more and more in the future. It seems to me that the subject is a very timely one. The question of depreciation is one that may not be as serious to electric-lighting companies as a great many may imagine, when the appreciation of land value, the interest-increment of the fund, the salvage value, and the very long life of some classes of investments are considered. The average rate of depreciation is probably not as large as a great many have considered it in the past, or as large as a great many figure it at present. There are probably a great many concerns who are taking care of depreciation in the shape of different kinds of funds, reserves, surplus, and so on, probably amply taking care of it, although they have no really good system for doing so. It seems to me it is much better to have a system, and the state commissions, or other authorities, will undoubtedly require more and more carefully prepared systems and more uniform systems. I think, as some of the other gentlemen have said, that where the property is thoroughly well maintained, where liberal charges are made for maintenance, practically the only depreciation that is serious is the one that Mr. Jackson calls obsolescence. Decrepitude is in a great many cases undoubtedly taken care of in the regular maintenance charges.

Mr. Harold Almert, M. W. S. E.: It is really refreshing to hear a paper of this nature discussed before a body which it is generally supposed is purely technical and pays no attention to the financial end of projects after they are completed. Many engineers plan for ample capacity and reliability of service without regard to first and ultimate cost, leaving to the commercial end the keeping down the cost to the proper limit.

The speakers this evening I think have all spoken from the standpoint of the large properties. There is another class, the small fellows, who have not the technical staffs to study out these problems and who have been working in the dark and are still so working on this subject of maintenance and depreciation and they are unknowingly doing themselves, their stockholders, and their bondholders a great injustice from lack of knowledge of this subject. The average central-station manager, I think, is to be criticized somewhat for his lack of effort in upholding rates in the past few years. It is really alarming to see the rate of decrease in charges for electric service in the past ten years, and especially when we note the enormous increase in the cost of labor, supplies, and machinery—in fact, the cost of everything else, including the cost of living. There has been a very decided increase in the cost of everything else except public-utility service, which has been going down at an alarming rate.

One speaker called attention to the fact that it is not necessary to consider supersession until the time comes, and I am reminded of the condition of the electrical industry some ten or fifteen years ago, and of a cartoon in *Puck* or *Judge,* or some such paper. A man going home late in the evening, shortly before Easter, a little the worse for wear, had a large box in his hand. He met a man coming in the opposite direction and they endeavored to pass each other, when the one with the box finally said, "For goodness' sake, don't stop me. Let me get home with this bonnet to my wife before it gets out of style."

While the condition of the electric industry was not exactly the same at that time, improvements in apparatus, due to advance of the art in the past fifteen years, came so quickly that it was not very far from the same situation as the man with his wife's hat. In fact, not more than five or six years ago, while visiting a big station in New York City, I saw them erecting the last one of eight or nine large reciprocating-engine units for which the station was designed, and at the same time that they were erecting this eighth (or ninth) unit they were taking out the first one to make room for a turbo-generator which had superseded it. As I stated before, there are a number of owners of public utilities who are principally interested in other lines and have not given proper study to this subject of depreciation, and who are unknowingly doing themselves and their stock and bond holders a serious injustice.

I have just come from the examination of a set of books on a property which wishes to issue some additional bonds, and in this particular case the fact is the plant investment account *on the books* is in the neighborhood of $5,000,000. Our engineers who made the physical valuation of the property finished their work the week previous and had given the property every consideration possible, having added the proper amounts for engineering, interest during construction, legal expense, and those various other items which are right and proper. They could not show an inventory to exceed $1,200,000 as a valuation of the physical property today. On examination of the details of that account and tracing its history, we found that several years ago, in that particular city, one plant was started, which was named, after the system, the Thomson-Houston Company; in another part of the city, another, named the Edison Company, and in another part of the same town, the Brush Company; Mr. Jackson's analogy of the wall paper fits in very nicely in this case. It was soon found that these plants were not able to supply the requirements of the people and that their apparatus was out of date. At that time more modern machinery had come into existence, and so the proposition was entirely revamped physically and covered with a new coating of wall paper, in the form of a consolidation and a new bond issue; they went on and utilized that wall paper for a time, wore it out a little harder in spots in the center and not so much on the edges, and in the course of a few years, two or three more companies had sprung up in the central part of the city, and at the end of another five years it was necessary to give the whole situation another coat of wall paper,—effect another consolidation, discarding all of that equipment, and start all over again with an entirely new equipment. So that in tracing the money that had actually been spent, it is true that they had spent in the neighborhood of $5,000,000, for which they can show at this time only $1,200,000. At the same time the officers of that company, for want of information, are actually satisfied with their present rates and believe that they are really earning not only operating expenses but also the bond interest on the last plaster that had been put on to the property; they were perfectly content and felt that they were doing well; in fact, so much so, that a year ago there was just a little bit more than enough to pay the bond interest and the 2% which they were paying on their stock, and not knowing what to do with the money they suddenly remembered that the majority of these officers, who had been officers of one of the underlying companies, did not get any dividends in 1901, 1902, and 1903, so they appropriated $58,000 of that money to the dividends which they thought were earned in those years but not paid. When it was suggested to them that there seemed to be no provision for a sinking fund and no provision for depreciation or any other items, they were, I believe, truly surprised that such was necessary. They had heard the terms but they had not seen the necessity of considering them in their property. As it happens, just at this time the examination is being made for the purpose of putting still another big plaster on the properties, for the reason that the community is very desirous of doing away with the unsightly poles and wishes to have the company put all wires under ground. The equipment which they have at this time is in first class physical condition and they serve the people in the way they should be served; but it is unsightly in their eyes, and for that reason they feel that it ought to be discarded.

I am not making an attempt to discuss the paper or the subject, but am simply trying to illustrate, by this case, the necessity for serious consideration of obsolescence, depreciation, maintenance, etc., which have been so well brought out by Mr. Jackson. I know we are all grateful to the author for the paper presented, and I think a more careful study of the subject along the lines suggested by Mr. Jackson and also by Mr. Duffy will be very beneficial to all of us and to those whom we serve.

Mr. W. L. Abbott, M. W. S. E.: There is one particular point which Mr. Jackson touched on, which particularly interests me because I particularly disagree with him.

Mr. Jackson states that the useful life of power-house machinery would not exceed fifty years, but to be conservative he puts it at twenty-five or thirty years. I have been in the electric lighting business for about twenty-five years, and in that time I have seen the entire equipment of the lighting companies rendered obsolete and junked about four times. It will interest me to see how Mr. Jackson will provide for that rate of obsolescence in a manner that will harmonize with his statement that such equipment is good for twenty-five to thirty years.

Mr. Jackson: If Mr. Abbott will carefully read the part of the paragraph to which he refers, he will find that he has not quoted me correctly. What is said in that paragraph is:

> * * * * "Let us consider a large high grade engine-generator set for alternating currents. Few of us would be willing to place at less than fifty years, the period during which such a machine should be physically capable of doing, under good care and management, the particular work for which it was designed; but no conservative engineer would allow, when estimating depreciation, that such a machine will have, in ordinary commercial electric service, a useful life of fifty years because advances of the art would inevitably affect its usefulness. In consideration of the great changes that have taken place in the past in apparatus for the generation and distribution of electric power, and the probable changes that will take place in the future, such a piece of apparatus cannot appropriately be allowed an estimated useful life of over twenty to thirty years." * * * *

If Mr. Abbott will consider the large, high grade engine-generator sets that have come within his experience he will see that the above statement is entirely within reason.

Mr. Franklin H. Reed (Assc. Mem. A. I. E. E., Editor of *Telephony*): Mr. Jackson has compressed a review of a very considerable number of points of interest into a brief paper. In doing so he is not only making a direct contribution to knowledge of the subject but, it is to be hoped, one which will have a still more valuable influence in extending the discussion and study of depreciation accounting, as an aid to the practice of sound finance.

Interest in this topic among operating men, at least in the telephone field, has greatly widened and increased during the past few years. A year ago last winter, it was very keen in certain sections of our north central states at the time sleet-storms were making their visitations. I recall one small company in Minnesota which preceded the addition of capital, like a layer of wallpaper, which forms Mr. Jackson's apt analogy, by raising its rates 25% after the wires tumbled down under a sleet load.

The possibility that depreciation funding will be omitted during the period of upbuilding is an interesting topic for discussion. In the telephone industry the process of upbuilding is practically continuous, and the company is confronted with the necessity of figuring on frequent expansions of plant. But usually within a moderate period the initial system has a very considerable earning efficiency.

During its period of early life, maintenance expense is very much lower per station than during subsequent years. So, although it may not agree with some present accounting theories, it is probable that many of the small plants would find it to their advantage to be a bit forehanded, as the saying goes, in providing their depreciation funds, and put the money away while current maintenance expenses are comparatively low, rather than to postpone the start to a later day.

There has been a tendency in the minds of some operating men to confuse the depreciation fund with maintenance expense. Maintenance expense is incurred to hold up the plant; the depreciation fund protects the investment. As long as inventive talent and organizing ability can command exceptional rewards, and real estate investments hold forth the possibility of unearned increment, the speculative element will enter into investments. Securities issued by public utilities will be obliged to offer a certain amount of speculative attraction in order to compete in the money market with other business. Yet it is an axiom, that any investment which appeals to the speculative element in human nature, presents a certain risk of losing which must be balanced against the hope of gain. The sentiment is coming to be widely held that public-service corporation funds should be characterized by safety,—investment with the speculative element reduced to a minimum. The public utility is peculiarly fitted to occupy the field of safe investment, owing to the slight liability to considerable reduction of income from any cause except bad management, and the steady and fairly regular expansion which accompanies the ever increasing natural demand for its service, which constitutes a modern necessity. If a public-service corporation accepts this view of its own investment standing, it irrevocably commits itself to the principle that an investor in its capital is entitled to withdraw his investment at his option. The property must be so managed that the man who pays in a dollar can take it out, and be sure that he will be able to do so one or ten years hence. Then he will have the same confidence in the safety and accessibility of his money thus placed as he does when it is put in the savings bank. This principle is the foundation of the ethical and business status of the depreciation fund.

An appropriate question for discussion, for some time to come, is likely to be the responsibility of the accountant in determining the actual rate of depreciation for the several classes into which a plant must be divided, as Mr. Jackson says, "in order that the average rate may be determined." While in all of the public utilities some parts of the plant will shift in character, so that obsolescence and inadequacy will have to be reckoned with in depreciation studies, yet we may well believe that certain other parts will be in use in a standard form and ratio, or approximately so, not only in present plants but in the ones which replace them.

For computing depreciation the engineer must have records, and a legitimate place for keeping such records is in the accounting departments of the operating companies. It will be interesting to see who will be the first to work out a satisfactory system of life accounting, which will give results of sufficient accuracy to be valuable in themselves, and at a cost sufficiently low to prove in the system.

Mr. G. W. Cravens: There are two or three points I would like to emphasize. It may have impressed some that this question is largely one of bookkeeping. Strictly speaking, all records are matters of bookkeeping, of course, but this matter of depreciation is more than that. A modern engineer has to be more than a designer and operator. It is also his business to see that the investments earn a fair return and are protected.

My own experience along this line has been largely with small plants, but my practice has been to divide this subject into three general heads:—maintenance, depreciation, and amortization, or, as it is sometimes called, a *sinking fund.* Depreciation proper is usually considered as meaning a reduction of value due to age, but it is really more than that. It applies to a process and, strictly speaking, it is a setting aside of a fund to cover contingencies, just as Mr. Jackson has brought out. Maintenance, on the other hand, is an entirely different affair and applies to making repairs and replacements during the life of the operation of the equipment of whatsoever kind it might be. Amortization is the provision of a fund which will equal the amount of the original investment at the end of a given term. My ideas on this subject are given quite fully—from the physical standpoint, at least—in the number of the *Electrical Review* of April 23, 1910. That is an article on the depreciation of electrical equipment which will give more information than I can give in two or three minutes.

But I will say that the points brought out by Mr. Jackson are all good, and even though perhaps we cannot all agree with all of them, I believe such questions as this should be discussed more freely than they are. The best way to find out facts, usually, is to start an argument. In the article referred to, I tried to start an argument by taking a stand against the *equal annual percentages* usually set aside for depreciation. I think that a sort of sliding scale should be followed rather than an equal division. For instance, you say the life of a piece of apparatus is twenty years. We mean by that that its average length of life will *probably* be that. We all know that as soon as a piece of apparatus is put into service its value—*market value,* if you please—immediately takes a drop. In fact, we know that as soon as a piece of apparatus leaves the shop we cannot get as much money for it as we had to pay for it. Now, if the life of the property is normally twenty years, the chances are that its depreciation, if one tried to dispose of it, would be a good deal more than 5% the very next day after you purchased it. So, I believe that instead of setting aside equal annual sums for depreciation, the sum set aside at first should be, say, 10% or 15 %. That is, when I say *set aside* I mean *charged on the books.* We know that we cannot set aside 10% or 15% of the value of the plant the first year, because probably we will not have it, but it can be charged against it the same as a loan, exactly, and carried on the books and wiped out later in the days called the fat years, or when money is being earned in sufficient quantities to make up these deficits. Then, along the middle period of the life of this apparatus we can come down perhaps to 5% or whatever is considered fair; and along toward the end of the apparatus, when it begins to go to pieces, rapidly increase the rate of depreciation again, so that at the end of the time, say twenty years, the total amount set aside equals 100%.

That is, I think, a new point of view to most of you, but I have tried it, and find it works out very well, for this reason: it gives a book value more nearly equal to the *actual* physical value at any minute.

Mr. Wray: Mr. Cravens has raised a very interesting point.

I am wondering how he would apply the principle to a plant that is being added to each year—whether that would not complicate the situation, and complicate the method of applying the principle.

Mr. Cravens: In that case, I would handle each piece, or rather each class of apparatus, on a different basis. For instance, the rate of depreciation of a street car is very different from that of the transformers in a station. When new apparatus is added, I would account for that piece of apparatus as I would when the equipment was first installed. It gives more headings in bookkeeping, but, on the other hand, it gives a more accurate record. Depreciation of each piece of apparatus according to its own value—I mean, not physical value but its relative value in the general scheme—rather than classing all the apparatus together. Take, for instance, boilers. They depreciate much more rapidly than the electrical equipment, and should not be treated in the same way at all. Classify the equipment according to the service, and enter that apparatus, and depreciate each class according to its probable life, as well as its age at the time at which the inventory is being made. Some concerns have tried the practice of making an inventory at frequent intervals rather than predetermining a rate of depreciation. Small concerns can do that, but the big ones find it too bulky, although it is a very accurate method.

Mr. J. R. Cravath, M. W. S. E.: One thing that has impressed me in the numerous discussions we have had on this depreciation subject the last few years, has been the difficulty of drawing a hard and fast line between what is maintenance and what is depreciation. I have heard my friend, Mr. Duffy, discuss that at length, and yet I must confess that I have not in my own mind, and I think many others have not, a very clear idea of where we should draw that line. When we replace a piece of packing in an engine-piston, that is evidently a case of maintenance. When we replace the engine itself, that is evidently a case of depreciation. But it is not always so easy to draw those lines in the different parts of the physical equipment of a plant. When we replace one or two poles, we usually consider it maintenance, but if we are going to replace a number of them, do we call it maintenance? It is somewhat a matter of bookkeeping, and it makes a good deal of difference who is keeping the books.

Mr. Weston: I think that Mr. Ubelacker covered that point quite thoroughly when he said that in his judgment depreciation should come under one head, and that maintenance should cover it all. I believe that it is ordinarily divided in this way: that the maintenance of a property is covered by ordinary repairs, which probably would cover the replacement of a few poles, but where an entire line would be maintained or replaced it would be termed a renewal. My understanding of the word depreciation takes in all forms of physical wear, all forms of obsolescence, and in ordinary every-day accounting or maintenance of the property it is divided into the two parts of ordinary repairs and renewals, and the two combined cover the entire field of maintenance and also the field of depreciation.

Mr. T. Milton, M. W. S. E.: This subject has interested me more from the definition standpoint than from the standpoint of real depreciation. It seems to be unanimous that it is necessary to set aside money or, on the books anyhow, set aside something to take care of the wear and tear. Some people call it depreciation and some call it maintenance. For myself, I like the definition that Mr. Jackson has given and the way he splits it up, because I have had to maintain that, and I have to do so nearly every day. The storage battery people claim that there is no depreciation on batteries, and I think that my argument has always been along the line of the definition which Mr. Jackson has given. He splits depreciation under two heads—decrepitude and obsolescence—and defines decrepitude as the gradual wearing out of apparatus which cannot be overcome by current repairs. Now, a battery is a peculiar piece of property. When a plate or a piece wears out, by putting in another one of those pieces the battery can be brought up to capacity. It does not pay to leave a plate or part of the battery in bad repair, because it throws the whole apparatus out of good order. The consequence is that by making continual renewals and keeping up the battery, we always class it under one head as maintenance. I believe there are pieces of apparatus which may have depreciation. For instance, I think the boosters and switchboards in the battery plant undoubtedly must have some depreciation, but in the battery proper, according to Mr. Jackson's definitions, I do not believe there is any depreciation.

It all comes back to the point, what do you mean by depreciation? When we begin to talk about depreciation and maintenance, everybody seems to have different definitions. Personally, I prefer Mr. Jackson's definition, because, under the obsolescence head, so far in the history of the lead storage battery at least, there has not been much change in the last twenty odd years; in fact, practically none; and certainly a battery plant can be maintained by current repairs. It does not deteriorate simply from old age.

Mr. E. N. Lake, M. W. S. E.: The hour is so late I will call attention to only one point. It seems that the discussion of the evening has centered entirely on depreciation. There is one question in connection with this matter of reserve that I would like to ask. One speaker of the evening refers to an adequate estimate of a suitable yearly contribution on account of required construction based upon the requirements that are likely to be imposed in the future by municipal ordinances. I would like to ask if he has any special basis for the application of the theory of probabilities by which he can arrive at what any given City Council is going to do?

Mr. Weston: Before Mr. Jackson begins his closure I would like to refer to his paper where he advocates the establishment of a reserve fund, or rather he advocates that in the determination of the life of an apparatus the depreciation and obsolescence feature be considered in calculating that life. In the remarks made by Mr. Ubelacker, he stated that he did not see the necessity or the justice in establishing a reservation fund to take care of the supersedence of apparatus, but that he thought where a piece of apparatus should be superseded on account of its inadequacy or for other reasons, the advantage due to the improved conditions resulting from the installation of the new apparatus should take care of the added investment. How is he going to provide for payment for the new apparatus at the time that it is installed, without a reserve fund or without adding it directly to capital account?

Mr. Ubelacker: I think that perhaps Mr. Weston did not catch the drift of the point I was making. I said if we are establishing a rate for service given, using as the basis for establishing that rate the cost of giving that service, why should we charge on the man, the customer, who is getting the service of plant A, which is going to be later superseded by plant B, the cost of superseding plant A, which gives an inferior service to plant B? Why is not the man to carry the loss which we have to take up when we put in the improved service, the man who gets the improved service? In other words, why is not that where the cost of that service ought to go in the rate? I am not saying that this is what we ought to do. I am asking why not? It is a question we have to come up against many times when a rate is being established. The other reason that I gave for the possibility of taking that view is the fact that the basis on which we supersede apparatus is that the superseding apparatus will pay its way by either its reduced cost of operation or its larger earning power, which answers Mr. Weston's question as to where we would find the money to take up the last of our charges, the difference between the new cost of the superseded apparatus and its selling value when superseded.

Mr. Weston: No, it is not made clear to me where the man that is going to buy that apparatus is to get the money to pay on the bill of lading or on a sixty or ninety day credit, and what disposition is the auditor and controller of the company going to make of that expenditure?

Mr. Almert: Mr. President, I cannot quite get the drift of Mr. Ubelacker's remarks either. I can remember when we used to ride in old horse cars in Milwaukee, without any heat in them and with only straw to keep our feet warm, a very short distance and very slow service by horse power, and the price was then five cents. Today they have the latest up-to-date cars with all conveniences, a first-class roadbed, a high speed running schedule, and very much better service, and the price is still five cents, or less. On Mr. Ubelacker's theory, I do not know in what section of the country we will operate, where the franchise will permit us to raise the rates when those conditions obtain or where we would have patrons that would stand for it and understand why the rates were increased. I cannot see where the money is to come from.

Mr. Wray: I would like to add another point, as I believe, against the position Mr. Ubelacker has taken, and that is in the question of improvements which are made to better the service without necessarily improving the earnings or reducing the cost of the service. It seems to me that the policy advocated would tend to delay improvements of the service or delay the adoption of methods or apparatus which would improve the service.

Mr. Ubelacker: I think that any over-estimate of depreciation is going to have exactly the effect mentioned. It is going to delay the adoption of improvements. That is one reason why I am very doubtful as to the good policy, either from the public standpoint or from a financial standpoint, of over-estimating depreciation, or of over-emphasizing it. The point just brought out—the fact that one is paying now for good, modern service transportation at the rate of four cents, where previously he paid five cents for a very much poorer rate of transportation—brings out the other point I was trying to make. There is no justice in our paying less now for a good service than we previously paid for a poor service, and the reason that we are doing it is just because you do not answer the questions I have asked here tonight, in the handling of rates. That is, what is the justice of assessing against the man in the early days the cost of superseding the apparatus which is giving the poor service, and then giving the man in the later days that gets the good service the benefit of the fact that the man in the earlier days has paid for that supersession. The man that gets the service ought to pay the cost.

Mr. F. Schumacher, M. W. S. E.: I would like to answer Mr. Ubelacker's question this way. In 1907 there were two companies —I will name them, for instance, the United States Steel Corporation and the Westinghouse Electric Co. The United States Steel Corporation made liberal provisions for a surplus fund and a depreciation fund. In the panic of 1907 it built up the Gary plant out of its depreciation fund and the Westinghouse Electric Co. went into the receiver's hands. So the Steel Corporation, I think, followed up Mr. Jackson's theory of finance and the Westinghouse Electric Co. did not. This simply shows where that leads to, if all profits are divided among shareholders, and no provision is made for an adequate reserve fund.

Mr. A. W. Stager: The present business I am engaged in with the Sanitary District is the purchasing end. Of course, I have been largely interested in the rates they are now making to the public. The point that has especially impressed me is the apparent disagreement of the various members present with Mr. Jackson's views. They all said it was a good paper but still they all had their own opinions about the subject. The question of depreciation seems to have many different angles,—many different quantities, I might express it. One man thought that maintenance was the greatest part of the charge. Another man thought depreciation should bear the larger portion of the charge. With our plant we have just lately installed a cost system that has enabled us to get at the exact facts in connection with the operation as well as the original investment of the plant, but those figures have not as yet been reduced to such a state that they can be put before the public in an intelligent manner.

CLOSURE.

Mr. Jackson: I want to emphasize the fact that one of the chief thoughts I have in presenting this paper is to get people away from the idea that depreciation may be treated as a secondary consideration and may be considered as a mere juggling of figures by the bookkeeper. What I wish to see is this matter of depreciation handled intelligently and logically, so that the books of the company will show the actual facts of the cost of service. I can feel entirely justified in going before any fair-minded person with a carefully considered scale of rates, if I can say these rates are fair because they are based upon the cost to the company to provide the service, and in these rates I have allowed for annual appropriations to the depreciation and reserve funds; the estimates for such annual appropriations are based upon as complete information as is available. And I can truly state that the actual cost to the company of the service is as estimated, notwithstanding that the company may spend during any particular year possibly only one-tenth or maybe one-twentieth of the average amount of money that must be appropriated annually for depreciation and reserve funds. I know that such annual appropriations are a part of the cost of the service, owing to the fact that the company must eventually have money to replace the plant that will go out of service from obsolescence or from decrepitude, or that they will require the money for some unforeseen contingency which we can only estimate. To deny this would be on a par with saying that the earnings from a successful mercantile business need not be sufficient to cover the cost of replacing the office furniture and fixtures, horses and wagons, and other equipment when these are worn out and no longer serviceable, and that the cost of such renewals might appropriately be taken out of the capital account.

I would like to emphasize what Mr. Almert said, that some companies today are allowing their rates to be forced down below a profitable level because they do not know the real cost to them of the service they are providing, or because they do not have the courage of their convictions, and the reason that they do not have the courage of their convictions is frequently that they have not intelligently and logically worked out what depreciation in plant actually means to them and what amounts of money they must in the near future pay out to replace plant that is worn out or that must be replaced for one reason or another. Today there are many plant managers who are worrying to know where they can obtain the money to replace parts of their plant that they know must be replaced this year or at some future period, because they cannot or should not float more capital to take care of those costs, and they have not accumulated funds for that purpose.

Another feature is this: suppose a company does not take care of the depreciation and reserve funds so that they can have appropriate apparatus for providing their service when their old apparatus becomes antiquated or worn out. They will be seriously handicapped if they are called upon to stand against competition from a new and ably engineered and operated competing plant, equipped with the best and most economical equipment, whether it is under private or municipal ownership.

The question of depreciation and appropriate reserve funds are not matters of mere bookkeeping. They are financial matters, it is true, but they are highly important financial matters, and their proper treatment is one of the factors that goes right to the heart of the successful operation of public-service corporations of today.

If, as Mr. Weston advocates, the factor of obsolescence is not included in the consideration of depreciation, one of the very important elements of depreciation is omitted, and those responsible for a company's welfare do not take full advantage of their right to keep the property of the stockholders in its best possible condition.

In reply to one of Mr. Ubelacker's questions, the patron of today is not asked to pay for the equipment of the patron of tomorrow under an appropriate arrangement of appropriations to depreciation and reserve funds, for he is simply asked to pay for the use of the property he is interested in. Any replacement that puts more costly plant in place of less costly should add to the capital value of the plant by the amount of its additional cost, and such additional cost does not affect conditions until the replacement is actually made.

In closing I wish to say that any consideration of depreciation and reserve funds, such as is found in this paper, must be considered as an annunciation of general principles rather than of specific applications. As is pointed out in the paper, though possibly not as fully as might be desired, every company must expect to have its fat and its lean years. But it is nevertheless highly important for the best interests of a company to know, within a reasonable degree of accuracy, what proper appropriations to depreciation and reserve funds are, so that they will know how much they are short of such appropriations during lean years and how much they must expect to appropriate when the fat years are at hand. This entails the fullest knowledge of their depreciation and reserve fund requirements and an adequate system of bookkeeping to show the facts.

October, 1910

ECONOMIC CONSIDERATIONS GOVERNING THE SELECTION OF ELECTRIC RAILROAD APPARATUS.

BY F. DARLINGTON OF PITTSBURG.

Presented June 7, 1910.

There is often great variance of opinion or serious doubt among engineers and railroad men as to the relative merits of the three electric railroad systems that are more or less in common use. It is the purpose of this paper to discuss the matter briefly from the standpoint of economy of construction and operation. It is not intended to discuss the economical value of electric motive power compared with steam power, except to point out at the outset that the high cost of electric equipment is the chief thing that prevents the rapid extension of railroad operation by electric power.

There is no general rule by which the cost of electrical equipment for railroads can be determined because this cost is affected by such a great variety of conditions; for some parts of the equipment it depends on the weight and frequency of trains and the power used per train and for other parts it depends on the length of track to be electrified and on local conditions.

There are three distinct parts in the equipment required for every electric railroad system:

(1) The electric power generating plant.

(2) The electric power transmission and distribution system, including substations or transformer stations.

(3) The motive power apparatus, viz., the electric locomotives and electric cars.

Of these three parts the cost of the power plant and of the motive power apparatus, which is the locomotives or motor cars, varies with the total amount of power required for train propulsion at times of heavy traffic movements. On the other hand, the cost of the power transmission and distribution system varies with the length of the track equipped, with the maximum total power required and with the maximum power that may be concentrated at any place on the line.

VARIATIONS IN TRANSPORTATION REQUIREMENTS.

Train Weights.—Railroad service varies according to the requirements of traffic and the motive power of railroads must operate trains of different weights from light single car trains of 25 to 60 tons each, as on interurban electric roads, to heavy freight trains sometimes of 1000 or 2000 or more tons each. Increase of train weight tends to reduce operating expenses, and consequently railroad practice is steadily making trains heavier and heavier.

Train Speeds.—Trains must be operated at varying speeds since some kinds of traffic demand higher speeds than other kinds, and on every railroad there are some places where it is safe and economical to run faster than at other places. To meet the needs for quick time and to utilize railroads to the best advantage, it is necessary that speeds be adjusted to passing conditions of tracks, or for grade, or for regard to cautionary signals, or for standing on sidings, or a thousand different and ever varying matters. Since the business of railroads is to move traffic in the greatest quantity and in the shortest time practicable at reasonable cost, train speeds must be kept always at the maximum that safety and economy will permit, and since conditions of safety and economy vary with every run and with nearly every mile of every run, the required speed varies from the lowest speed or standing still to the highest speed and therefore railroad motive power should be economical at all speeds.

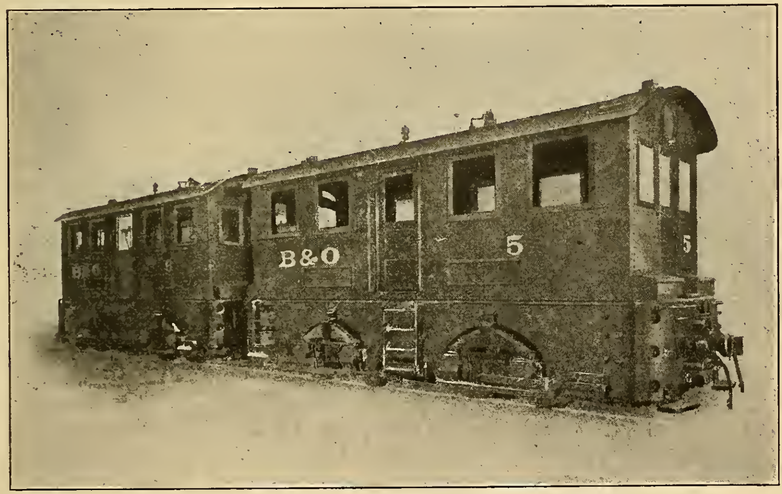

Fig. 1.—B. & O. R. R. Co., D. C. Electric Locomotive for Tunnel Service in Baltimore.

DENSITY OF TRAFFIC.

The density of railroad traffic may be anything, from one train each way per day on some roads, to as many trains as can be crowded over the tracks on some other roads. On some roads the traffic may be best served with single cars, as on interurban trolley roads or where gasoline motor cars are used, while on other roads it may be best served with maximum weight trains, either passenger or freight, as is common on many main lines.

POWER PER TRAIN.

This depends, of course, on the weight and speed of trains, on the grades to be climbed, on the stops and starts required, etc.

Since the total power and the tractive effort required vary according as the train is standing still, or is being accelerated, or is running at maximum speed, or is climbing a grade, or is coasting down grade, the power and tractive effort are constantly varying from zero to maximum. A locomotive of 1000 H. P. will handle a 1000 ton train under certain conditions of speed grade, etc., but under other conditions 1000 H. P. or more may be required for a 250 ton train, or a 50 ton electric car may in certain kinds of service require 400 to 500 H. P. per car to make its schedule.

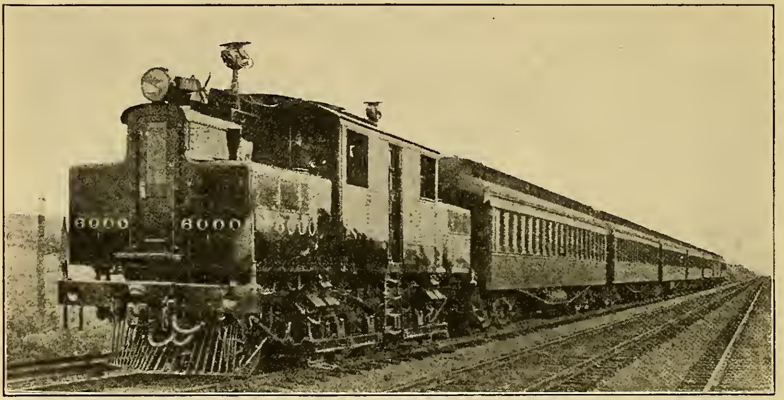

Fig. 2.—N. Y. C. & H. R. R. R., D. C. Electric Locomotive and Train in New York City Terminal Service.

AMOUNT OF LOCALIZED POWER REQUIRED ON RAILROADS.

Modern steam railroad trains on main lines use locomotives capable of delivering 700 to 1400 H. P. or more each, and trains are often passing or following or double headed so that even on single track roads 2000 to 4000 or more horsepower may be required by trains within comparatively short distances of each other.

Wide variations in all of the above factors, that is in train weights, train speeds, density of traffic, power per train, and power concentrated at local points on a railroad, may occur at different times and places on a single railroad or section of track. All of these conditions must be met by railroad motive power.

CHOICE OF SYSTEMS.

Which of the three well-known electric systems, each of which has its ardent and often partisan advocates, is best adapted to meet all of the variable conditions?

The systems are:

(1) The Direct Current System.
(2) The Single Phase System.
(3) The Three Phase System.

EACH SYSTEM DIFFERS RADICALLY FROM THE OTHERS.

The electric motors used in each system are fundamentally different from the motors used in the other two systems, and require a different kind of electric current for their operation, and this necessitates for each system different apparatus for the distribution of the electric power.

I propose to discuss the relative merits of the three systems briefly from the standpoints of reliability and of economy of construction and operation.

POWER PLANTS FOR THE THREE ELECTRICAL SYSTEMS COMPARED.

The electric power generating stations are usually steam turbine or hydro-electric plants. Gas engines have not come into extensive use for furnishing power to electric railroads. The cost and efficiency of the power plants for the three systems do not differ greatly, for although single phase generators are more costly than the three phase generators used for the other two systems, the total engine and boiler power usually has to be somewhat greater for direct current and three phase than for single phase operation. This is because the losses are greater in direct current trolleys or third rails, and in direct current sub-stations than in single phase trolleys and transformer stations, and because three phase motors under ordinary railroad conditions make greater fluctuations in the load on the power plant than single phase and direct current motors do. In spite of the greater capacity in engines and boilers for D. C. operation of railroads than for single phase, it may often occur that the K. V. A. or apparent electrical output will be greater for single phase than for direct current service due to the difference in the power factor of the current supplied.

For three phase main line railroad electrical operation the power plant will generally be somewhat larger and more costly than for either direct current or single phase. This is especially the case where variable heavy grades are encountered or where heavy trains are frequently accelerated, and is caused by the characteristics of three phase motors which tend to make high peak loads on the power plant when worked at the widely varying tractive efforts and speeds usual in railroad work. This will be discussed later.

Under most conditions, the total of the variations described does not cause a large difference in the cost of the power plants required for the three electric railroad systems.

Ordinarily the cost of steam turbine plants for railroad electrical operation is somewhere in the neighborhood of 25% to

40% of the total cost of electrical equipment. It more closely approaches the larger proportion of the whole cost when the traffic is dense, requiring a large supply of power per mile of track, or where high tension single phase trolleys are used, which by their relatively low cost reduce the total cost of electrical equipment, thereby making the cost of the power plant a larger proportional part of the whole electrification cost.

POWER TRANSMISSION AND DISTRIBUTION LINES AND EQUIPMENT, INCLUDING SUB-STATIONS OR TRANSFORMER STATIONS, COMPARED FOR THE THREE ELECTRIC RAILROAD SYSTEMS.

The power transmission and distribution system forms the link between the power plant and the electric locomotives or cars. It consists of trolley lines or third rails, of feeder cables, of track bonding, of sub-stations, and of high tension transmission lines. The aggregate cost of these items is the largest or at least a very large part of the total cost of electrification for heavy railroad operation. Where direct currents are used the power transmission and distribution apparatus generally costs more than either the power plant or the electric locomotives and motor cars, and is liable to be between 40% and 60% of the total electrification cost, and is especially high where heavy trains are to be operated requiring large units of power distributed over long sections of track. Under these conditions, even where advantage is taken of the most modern improvements, using 1200 volts direct current on trolleys or third rails, the cost of direct current distribution apparatus is still the largest cost item for electrical equipment.

Where single phase apparatus is used the electric power transmission and distribution system is greatly simplified and cheapened. A single high tension trolley wire is substituted for the trolley wire or third rail and feeder cables of the direct current system, and static transformer stations are substituted for direct current substations in which there are both static transformers and rotary converters or motor generators. The single phase trolley system is equally suitable for light infrequent service and for heavy dense service or for large units of power infrequently operated. The sub-stations are widely separated, and their cost, as well as the cost of the distribution conductors, is much less for single phase than for direct current, so that the combined cost of the substations, and transmission and distribution conductors, may be fairly stated under average railroad conditions to be about one-quarter to two-thirds as costly for single phase as for direct currents.

Where three phase apparatus is used, high tension alternating current trolleys are employed and three conductors are necessary to carry the current for three phase motors, so that two separately insulated trolley wires are necessary in conjunction with the track rails.

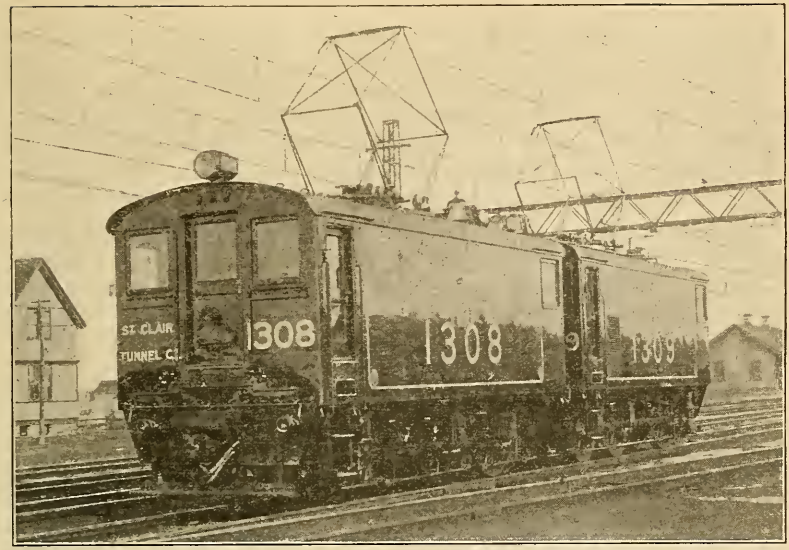

Fig. 3.—St. Clair Tunnel, G. T. Ry., Single Phase, A. C. Electric Locomotive.

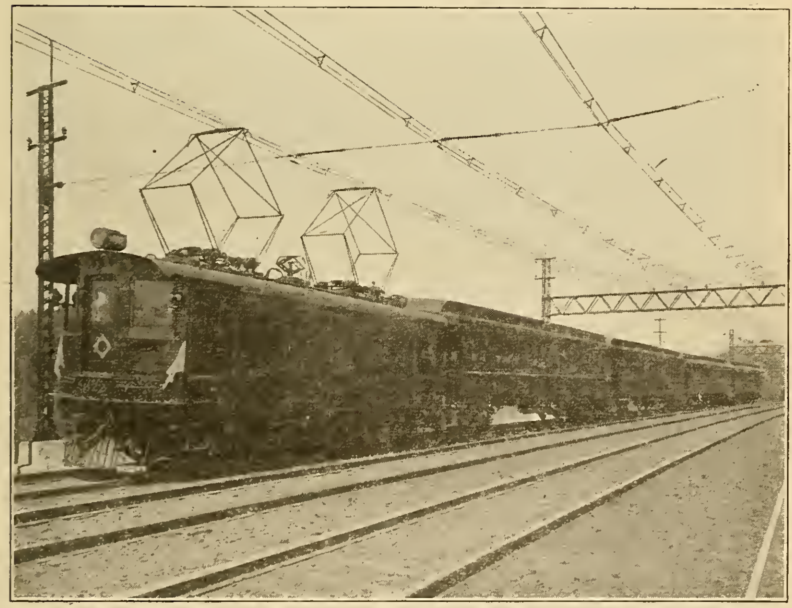

Fig. 4.—N. Y., N. H. & H. R. R., A. C. and D. C. Electric Locomotive and Passenger Train, New York City Terminal Service.

Three phase motors, as will be hereafter explained, can be built for working on higher potentials than can either direct current motors or single phase motors as ordinarily used. For this reason the potential employed on three phase trolley lines is usually applied directly to the motors without intermediate reducing transformers carried on the locomotives or cars. The desirability of working the motors without transformers, combined with the difficulty of separately insulating two trolley conductors for very high potentials, has generally prevented the use of as high potentials on three phase trolleys as are common on single phase trolleys. The latter are often built for 11,000 volts potential on the trolley, while according to present practice 3300 volts is usual and 6600 volts is high for three phase trolleys, though in the latter case reducing transformers are generally used on the trains.

Three phase motors for their successful operation under the varying loads encountered in railroad work require more uniform potential supplied to them than is required by either single phase motors or direct current motors, and in order to maintain better potential regulation on the trolley at the relatively low voltages at which three phase trolleys are generally operated as compared with single phase trolleys, it is necessary to locate transformer stations closer together on three phase lines than on single phase lines. For heavy trains the number of transformer stations will generally be more than double as many, and under certain conditions, three or four times as many for three phase as for single phase installations.

There is another thing about three phase transformer stations for railroads that is becoming more important than it was a few years ago when it was not practical to use as high a potential on transmission lines as can be advantageously used today. Three phase transformer stations require either one three phase transformer or three single phase transformers. It is much more costly to build one very high voltage three phase transformer or three single phase transformers than one single phase transformer of the same aggregate output. In other words, the cost of transformers per kilowatt of capacity is very much greater for three small units than for one large unit, especially when they are for very high primary potentials such as 100,000 or 110,000 volts. It is now well established that 110,000 volts or thereabouts will be widely used in large long distance power transmission schemes; the increase in potential over the practice of a few years ago having been brought about largely by improvements in line insulators, especially of the suspended type.

I cannot state just what the relative cost of three phase and single phase power transmission and distribution systems will average for the ordinary requirements of railroads, but it is clear that with two trolley wires for the three phase system instead of one wire as for single phase, and with transformer stations two or three times as frequent for the three phase as for the single phase system, the cost for the three phase system will be considerably increased, and will probably average somewhere from 30% to 80% more for three phase than for single phase.

RELATIVE WEIGHT AND OPERATING CHARACTERISTICS OF DIRECT CURRENT AND OF SINGLE PHASE AND OF THREE PHASE ELECTRIC RAILROAD MOTORS.

The three distinct types of motors used in railroad work determine the three standard systems, that is, the direct current system, the single phase system and the three phase system, and the motors all differ in cost and weight and method of operation.

Direct Current Motors.—The different types of motors may be conveniently compared by taking the direct current motor as the basis of comparison, since it is the oldest and best known in railroad work. It should, however, be noted in this connection that only within the last few years have direct current railroad motors been commonly built with so-called commutating poles and they are now known as inter-pole motors, and the new construction has greatly improved them. Formerly the capacity of direct current motors for heavy sudden overloads was limited chiefly by commutation, and the maximum voltage for which they were practically built was somewhere between 600 and 700 volts. The use of interpoles has considerably increased this limit, especially for large motors, and has largely done away with sparking on the commutator and flashing over, so that now overheating is the principal

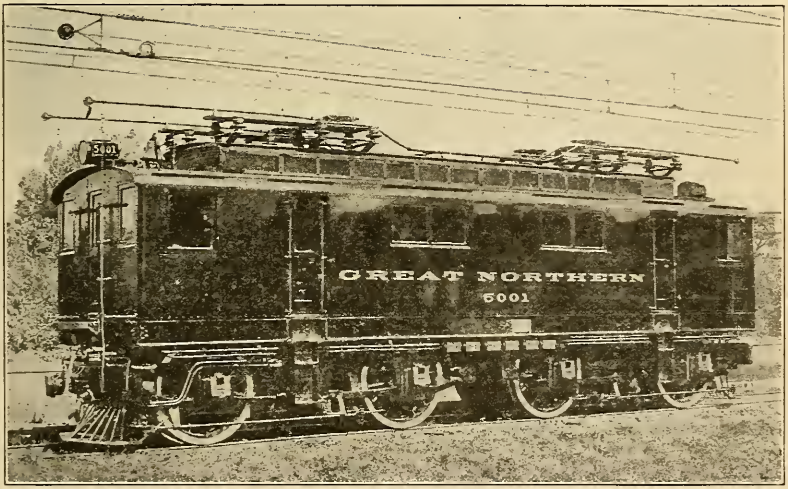

Fig. 5.—Great Northern R. R., Three Phase Electric Locomotive, Used in Cascade Mountains, Tunnel Service.

thing that limits the capacity of direct current motors of the latest design.

Single Phase Motors.—Single phase motors for railroad work are very similar in construction and in operating characteristics to direct current railroad motors. They are series wound, variable speed motors, and have compensating windings. Their compensating winding is differently arranged from the inter-pole windings of direct current motors, but performs a similar function which is to improve commutation, and at the same time it improves the power factor by reducing the self-induction of the motors.

Single phase motors are generally designed to work with variable voltages up to about 350 volts maximum applied to the motor, and experience has pretty well demonstrated that when everything is considered, 15 cycles or thereabouts is the best current frequency to employ.

High potentials are used on single phase trolleys and whatever the potential may be, whether 11,000 volts or more or less, the potential is reduced for the motor by transformers carried on the locomotives or motor cars. There is one type of single phase motor called a "repulsion" motor that is used in Europe to a limited extent. It is practically a motor and transformer combined and is heavier than ordinary single phase motors, but 11,000 volts, which is a common and economical single phase trolley voltage, is too high for economy and safety on repulsion motors without separate transformers.

An important difference in operation results from the difference in the motor control apparatus used for direct current and for single phase motors. Direct current railway motors are governed to vary the speed and tractive effort by connecting them in series and in parallel, by varying the field strength, and by inserting resistance in the circuits to regulate the flow of the direct current. Single phase motors are governed in speed, etc., by applying varying potentials to them from different potential taps on the transformer from which they get their current supply. Thus the transformers serve the double purpose of reducing the potential for the motors and varying it to govern the speed.

Single phase railroad motors are heavier and more costly than direct current railroad motors of the same capacity. Designers state that the difference is somewhere between 10% and 25% in weight and 25% to 50% in cost in favor of direct current motors as compared with single phase motors. The transformers required for single phase electric locomotives will generally constitute about 5% to 10% of the total locomotive weight, and the motors themselves will generally constitute about one-quarter to one-third of the locomotive weight. Additional weight seldom has to be put into the locomotive frame and running gear to carry the extra weight of the transformers and single phase motors when compared with direct current motors, because when the locomotive frame is designed with sufficient strength to withstand the shocks encountered in operation it is strong enough to carry all the load put upon it with single phase apparatus. There are so many conditions entering into the design of electric locomotives that it is very difficult to determine an average difference in weight between direct current and single phase designs with any reasonable approximation. For one thing, the need for series parallel control with direct current makes it necessary to always use either two or four motors to get an even number for connecting in series, when one or three motors might otherwise be lighter and more convenient, and of course there is no need for series parallel control with single phase motors. Then again the entire weight of any electric locomotive is sometimes necessary to get sufficient adhesion to the track to prevent slipping the driving wheels. This occurs in many designs of single phase freight locomotives so that if the weight were not in the mechanism, cast iron or other weights would have to be added to get adhesion.

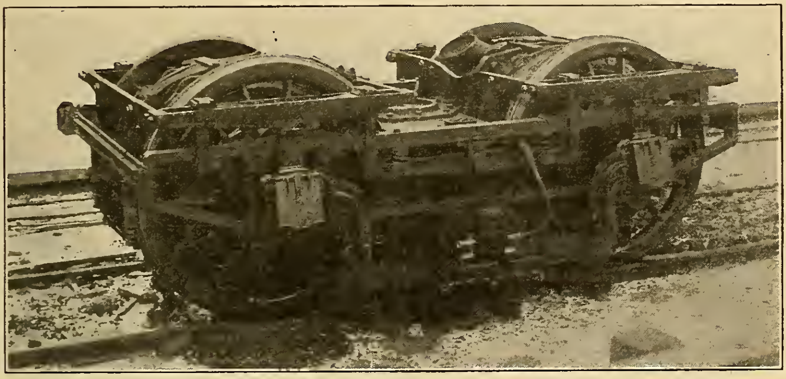

Fig. 6.—N. Y., N. H. & H. R. R., Single Phase, A. C. and D. C. Motors Mounted on the Truck.

In locomotive design we might perhaps reasonably say that if single phase motors are 25% heavier than direct current or three phase motors, the additional weight would be 8% of the weight of the locomotive and that this weight and 7% additional for transformers would make single phase locomotives 15% (more or less) heavier than direct current locomotives.

As already explained this extra weight will often not be objectionable from an operating point of view for freight locomotives, as it may be necessary to secure adhesion, but extra weight of machinery of course always makes extra construction cost, and it will almost always be objectionable in operation, as well as in first cost, with high speed passenger locomotives. I want to caution you that 15% is not a uniform factor for difference in weight between direct current and single phase locomotives for, under some circumstances, single phase locomotives may actually be lighter than equivalent direct current locomotives, or, on the other hand, under certain circumstances they may be more than 15% heavier than direct current locomotives.

PROPORTION OF THE COST OF ELECTRIC LOCOMOTIVES AND ELECTRIC EQUIPMENT OF CARS TO THE WHOLE COST OF RAILROAD ELECTRIFICATION.

It is difficult to give an approximate ratio between the cost of electric locomotives and electric apparatus on motor cars and the whole cost of equipping railroads for electrical operation.

For complete divisions of 100 miles or more on a single track main line railroad, where the trains are heavy and frequent, the cost of electric locomotives may be 25% to 40% of the total cost of electrification, but where the trains are lighter and less frequent this will be reduced to say 15% to 25% of the total cost. On this basis, if single phase locomotives cost more than direct current in proportion to twice the difference of their weights, or say they cost about 30% more, this difference in cost between single phase and direct current locomotives will amount to about 4.5% to 12% of the total cost of railroad electrification, but under ordinary conditions this is many times offset by the higher cost of power transmission and distribution by direct currents than by single phase currents.

On interurban electric roads, operating cars at one hour to one-half hour headway, the cost of the motors and electric equipment on the cars for direct current apparatus may be about 5% to 8% of the total electrification cost, and it is about one-quarter to three-quarters greater for single phase apparatus, including transformers, etc. On interurban lines except where they are very short the difference in cost between direct current and single phase motors is generally more than offset by the saving in cost of single phase power transmission and distribution apparatus, and on long interurban lines the difference is a good many times offset even where 1200 volts is used for direct current distribution.

THREE PHASE MOTORS AND THE EFFECT ON RAILROAD OPERATION OF THEIR CONSTANT SPEED CHARACTERISTICS.

Three phase motors, unlike direct current and single phase motors, tend to maintain constant speed at all loads. They are light and durable and cheap to build. Their advocates claim that on their continuous rating they are lighter and cheaper than direct current railroad motors of the same capacity. I am not certain on this point as regards weight, especially since direct current motors have been so greatly improved by commutating poles and improved design. Large size three phase motors have somewhat greater continuous horse power capacity than direct current railroad motors of the same outside dimensions, but they are usually heavier than direct current motors of the same dimensions. In any event, it is entirely immaterial for railroad work how the two types of motors compare at their continuous rating, because there is very little railroad work in which the motive power is operated at a constant rating or at uniform speed and tractive effort. The important consideration is, which motor is the best, the lightest, and the cheapest for the varying speeds and tractive efforts required in propelling railroad trains. Simple three phase motors are very inefficient at all speeds but normal constant speed, except where a certain device is employed by which it is possible to operate three phase motors at good efficiency at exactly half normal speed, or by another device at exactly double normal speed. Each of these devices, which are known as cascade connections and pole changing devices, require special appliances, and the use of both on one locomotive or motor car in order to get good efficiency at both half speed and double speed as well as at normal speed would be very troublesome, except possibly for low voltage motors for which transformers would have to be carried on the locomotives. Neither of the devices give good efficiency at intermediate speeds or at starting, and as a consequence three phase motors are not so well adapted as other railroad motors for work requiring frequent starting or frequent variations in tractive effort and speed. Other speed combinations than the above are possible but add still further to the complication.

One of the results of constant speed operation, as I mentioned before, is to cause very heavy demands on the power plant when heavy traction is needed. This may be best made clear by referring to a specific condition. Suppose a 2000 ton train is running at thirty (30) miles an hour on a level track, it will require 14,000 lbs. tractive effort to propel it. The horse power exerted will be 1120. If the same train encounters a 1% up-grade the tractive effort required will be 54000 lbs. and at the same speed, namely 30 miles an hour, the horse power exerted will be 4330 which would make a heavy peak demand on the power plant, and this could be reduced only by using a half speed device. There is another important thing to be considered where constant speed is maintained, whether it be 15 miles per hour or 30 miles per hour or any other constant speed, and that is that no advantage can be derived from velocity head, or what engineers call a "running start." If the speed is constant, the extra work on grades must be supplied just as it occurs without assistance due to momentum, and corresponding power must be supplied by the power house, resulting as in the previous case in heavy peak loads. But even aside from the motors and power plant there are very few instances where the best economy and safety can be had by running trains at a constant speed. There are places where it is desirable to run fast and other places and occasions where it is best to slow down and in practical railroading these conditions are encountered continually.

The variable speed characteristics of direct current and single phase motors readily permit a reduction in train speed when the tractive effort is increased, in fact unless controlled by the motorman, these motors will automatically reduce in speed with increased tractive effort, thus helping to keep down the total power demanded at the time that tractive effort is greatest. On the opposite side of the case, where the track is level and straight and high speed is desirable, a three phase motor cannot exceed a certain fixed speed, whereas a variable speed motor, especially a single phase variable speed motor that can be supplied with extra high potential from *over voltage taps* from the transformer, can take advantage of this opportunity to make extra good time; also trains equipped with variable speed motors can take advantage of velocity head or a running start in climbing short grades.

RELIABILITY OF ELECTRIC RAILWAY APPARATUS.

Reliability of motive power is of prime importance in railroading and any acceptable railroad motor must be reliable. Fortunately experience has established a pretty good degree of reliability for electric motive power.

Reliability of Single Phase Motors.—Much speculation and some doubt has been current regarding the reliability of single phase railroad motors. This should be set at rest by the results accomplished with them.

The largest single phase installation is on the New York City Terminal of the New York, New Haven & Hartford Railroad, where there are 40 or 50 1000 H. P. single phase locomotives in interchangeable operation between 11000 volts, 25 cycles, single phase current and 650 volts direct current.

This installation is demonstrating a high degree of reliability, not only for the motors, but for the entire electrical plant and equipment. On some days every electric locomotive has been in service, none being in the repair shops. Such a thing would not occur with forty or more steam locomotives. The number of electric locomotive miles made per motive power delay on the New Haven road has averaged, for several months at a time, one failure or delay in 15000 to 17000 locomotive miles. This is two or three times as many miles as is averaged per motive power delay with steam locomotives in the same kind of service.

The heavy single phase freight locomotives in service on the Grand Trunk Railway in the Detroit River Tunnel between Port Huron and Sarnia likewise give very reliable service.

Including interurban electric roads there are over twenty (20) single phase electric systems in operation in America, and over twenty-five (25) in Europe, and while minor difficulties have been encountered in some places an excellent operating reliability has been demonstrated for single phase apparatus.

Reliability of Three Phase Motors.—There is not so much practical railroad experience upon which to base judgment regarding the reliability of three phase motors as there is for direct current and single phase motors, but such railroad experience as there is, together with the extensive use of three phase motors for industrial work, points to an excellent degree of reliability that is unexcelled in any type of motor.

Reliability of Direct Current Motors.—The wide use of series wound direct current motors by railroads has thoroughly established their reliability.

COST OF MAINTENANCE OF ELECTRIC MOTORS AND LOCOMOTIVES.

Time will not permit much discussion of locomotive maintenance costs, but experience has demonstrated that it will average less for well constructed electric locomotives of all types than for steam locomotives.

In America the maintenance cost of the heavy direct current and single phase electric locomotives in use on various railroad systems is low in all cases. The roads using heavy electric locomotives are:

(1) The Baltimore & Ohio R. R.—Direct current locomotives used in tunnel in Baltimore.

(2) The New York Central R. R.—Direct current locomotives used on New York City Terminal.

(3) The New Haven R. R. interchangeable single phase and direct current locomotives used between New York City and Stamford, as already mentioned.

(4) The Grand Trunk Railroad.—Single phase locomotives, previously mentioned, used in the Detroit River Tunnel.

An interesting tabulation of the comparative cost of repairs for steam and electric locomotives has recently been published by Mr. L. R. Pomeroy in a paper presented before the Engineering Society of Columbia University. He segregates the items of repair cost for both steam and electric locomotives and gives the total cost of repairs of electric locomotives at about 40% of the cost of repairs of steam locomotives. He gives a little over one-third of the total cost of electric locomotive repairs as belonging to the motors, the remainder being for repairs of running gear, for painting, etc.

It is reasonable to suppose that single phase motors being more costly and somewhat heavier than direct current motors will cost more for repairs, but even if the cost of repairs on single phase motors should be 25% more than on direct current motors, this increase will add less than 10% to the total cost of locomotive repairs, provided Mr. Pomeroy is correct in his estimate, which gives the repairs of electrical machinery as three-eighths of the total cost of electric locomotive repairs. Likewise for three phase locomotive, since the repairs on the motors are only a small part of the cost of repairs on the whole locomotive, the possible saving by the use of three phase instead of direct current or single phase motors can never be a relatively large item. As regards motor cars the cost of repairs of the electric equipment has long been known to be very low.

EFFICIENCY OF DISTRIBUTION SYSTEMS COMPARED.

Brief mention has already been made of the difference in efficiency between the direct current and alternating current electric power distribution systems, but without giving relative figures.

All moderate and large size direct current railway systems employ rotary converter or motor generator sub-stations located at frequent intervals along their tracks to change the alternating current from the high tension lines to direct current for the trolley or third rail. The apparatus in direct current sub-stations includes moving machines that are necessarily operated much of the time under light loads; also the drop in the direct current trolleys or third rail at time of heavy loads is large, and the average result is that on direct current systems much electric power is lost between the power house and the trolley wheels or other collecting devices on the trains. On many large direct current railroads this average loss in power amounts to 40% or 50%, more or less, but is seldom as low as 35%. These are average losses and indicate the all day efficiency of the power transmission and distribution systems, and should not be confused with the loss at times of heavy load, or so-called *peak load,* on the power house, which latter loss is the amount by which the maximum power house output exceeds the sum total of the electric power taken simultaneously by the trains.

With the single phase and the three phase railroad systems the loss in electric power transmission and distribution is very much less than with direct current. On the large single phase installation of the New Haven road no transformer stations are used, as the current from the generators is conducted directly to the locomotives. The same thing is true in the single phase plant of the Grand Trunk Railroad at the Detroit River. The transmission and distribution losses at these places probably average less than 5% and even where transformer stations are used with single phase apparatus the losses are small, but are somewhat greater than 5%. The above statements about the efficiency of single phase distribution apply also to three phase distribution, but in a lesser degree because while both systems employ transformer stations without moving parts, three phase stations have to be closer together than single phase stations and consequently the transformer losses are greater in the aggregate.

EFFICIENCY OF THE THREE TYPES OF MOTORS COMPARED.

A comparison of the full load efficiency of the three kinds of motors show several percent, probably 3% to 4%, in favor of direct current and three phase motors compared with the single phase, and this difference is increased 2% or 3% by the losses in the transformers used with single phase motors, but this difference is partly, or wholly, offset by the superior efficiency of the control of single phase motors which makes no use of resistances to cut down the current when starting and when running slow, as is done with direct current and three phase motors. In any event whether or not the lower full load efficiency of single phase motors and transformers as compared with other motors is entirely offset by difference in the efficiency of control, this difference in efficiency is very small compared with the difference in efficiency of the power transmission and distribution systems which is in favor of the single phase system as already described.

DIRECT CURRENT SUB-STATIONS, OPERATING AND MAINTENANCE COSTS.

There is one large item of operating labor and maintenance cost that must not be overlooked and which is necessary where heavy direct currents are used, but that has no counterpart in single phase and three phase operation. It is the attendance and repairs of the moving machinery in direct current sub-stations. This is a heavy expense, and for ordinary conditions will run between $2000.00 and $3000.00 per sub-station per year.

UNIFORM ELECTRIC RAILWAY SYSTEM.

Transportation constantly requires interchange of traffic between railroads, and this makes interchange of appliances and uniformity of systems highly desirable even if not absolutely essential. The use of special appliances to gain a slight advantage in some particular limited case will not be justified in railroad work, if a standard and uniform system can be found that will economically and satisfactorily meet all of the many demands on railroad motive power. A choice between the three existing systems should not be based upon consideration of those parts of the system in which there is no great difference in cost or efficiency or in their practical operation. It has been pointed out that (except in the matter of operating three phase motors) the difference in these regards between the three systems is not nearly so great in the power houses, or in the electric motors on the trains, as it is in the apparatus for the transmission and distribution of electric power from the power house to the trains. For ordinary railroad conditions the transmission and distribution apparatus is the most costly part of railroad electrification and is the part in which there is a vast difference between the different systems. If we could entirely eliminate the cost of this part together with the losses sustained in delivering electric power from the power house to moving trains, train propulsion with electric power would be so much more economical than with steam that steam locomotives would be supplanted by electric locomotives just as steam engines in industrial plants are being supplanted by electric motors receiving power from large central stations.

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There is no present prospect of such a perfect wireless method of distributing electric power from power houses to railroad trains, but highly efficient and reasonably economical apparatus is available for the work.

THERE SHOULD BE AS LITTLE DEAD WEIGHT AS POSSIBLE ON THE WHEELS AND AXLES.

I will next mention a few important points to be considered in connection with electric locomotive designs.

You all know, in a general way, how the motors are mounted on the earlier designs of street-cars and interurban trolley-cars. Referring to the single reduction geared motors, the motor is suspended horizontally with one end carried on a bearing that rests on a car axle, and the other end is mounted with some form of spring-support resting on the truck-frame. This results practically in dividing the weight of the motor between two supports; one of the supports is the motor bearing on the axle, and the weight of the motor at this point is not spring-supported, so that any shock or blow, due to irregularities in the track or other causes, is transmitted directly to the heavy motor, and, conversely, whatever blow is transmitted to the motor is returned with equal force to the track, since for every action there is an equal reaction. It is obvious that the force of the blow struck will depend on the amount of the irregularity in the track, on the velocity with which the wheel strikes it, on the weight of the wheel and axle, and the weight that is attached inflexibly to the axle. Therefore, adding half of the weight of the motor to the axle in the manner just described increases the force of the blow of the wheels upon the rails. The other half of the motor, being carried on springs, rides easily on the track.

Consider for a moment the condition regarding weight on axles of steam-railroad rolling-stock. On steam locomotives the weight that bears upon the track without spring-supports intervening, is only the weight of the wheels, axles, and journals, since the weight of the locomotive-frame is carried by springs resting on the journals. Also there is some weight due to connecting rods which I will mention later, but the entire dead weight, or the weight that is not spring-supported in a steam locomotive, is a relatively small part of the total weight. The same is true of steam-railroad cars. All of the weight of the cars, excepting the wheels, axles, and journal boxes, is supported on springs.

Some people have had the impression that the most serious single cause for wear on steam-railroad tracks is the unbalancing due to the reciprocating motion of the locomotive cross-heads, connecting-rods, etc. This has always been balanced as far as possible, but it is not possible to completely balance it, and for this reason many people confidently expected that electric locomotives and motors which had no reciprocating parts would be far easier on the track than steam locomotives. The unbalanced effect of steam locomotive reciprocating parts is undoubtedly an important source of track-wear, but when the balancing is properly done this source of trouble can be very fairly well taken care of.

Experience with electric motor-cars and locomotives did not at first wholly fulfill the early hopes of electric motor advocates for railroad work. When heavy cars were operated at high speeds, it was found that the track-wear was much higher than anticipated, and it is evident that the dead weight of half of the motor on the axle is a very serious cause of increased track-wear, especially with high-speed trains. Some of the most skilled designers of electric locomotives and motor cars are strenuously discouraging the use of any construction for high speeds that adds dead weight (by which I mean weight that is not spring-supported) to the weight of the wheels and axles. There are two practical ways of avoiding this,—one method is called the quill suspension, the other is the side-rod construction to be described later on in connection with the electric locomotives of the Pennsylvania R. R. New York Terminal.

For the quill suspension, a tube or sleeve is placed around the axle between the wheels. The hole in the tube is considerably larger than the diameter of the axle. Flanged heads or arms are shrunk on to the ends of the tubes, and springs are inserted between the flanges or arms and the wheels so that the tube—or quill as it is called—is supported by springs with the shaft central through the hole in the tube. The springs permit a certain latitude of motion up and down and in a circular direction up to the limit of spring-compression or extension. In some recent designs of motors, the total clearance between the axle and the inner side of the tube is 1½ in. For gearless motors, the armature is built up on the tube—or quill—and the tube is the armature axle and runs in the motor bearings. The weight of the motor is balanced on springs, or on a frame that is supported on springs, the whole weight of the quill, the armature, and motor thus being spring-supported. With geared motors the gear is carried on the quill, as is also one end of the motor itself, thus securing a spring-support instead of making a dead weight on the axle.

This construction has been found very effective for relieving the force of the blow of the wheels when striking irregularities in the track, and effectively reduces the track-wear. The importance of having no dead weight carried on the axles increases as the operating-speed increases, and it is very essential at high speed. I believe that few people realize how essential it is until they learn from experience and observation. The pounding due to a reasonable amount of extra dead weight on the axle may not be serious to the track or the motors up to 35 miles per hour, more or less, but becomes very hard and must cause serious wear at speeds of 60 miles per hour or over, and where the dead weight is great it will be a serious factor at 50 miles per hour or over.

It does not require a very lengthy description to show how the dead weight is relieved in the case of side-rod locomotives. In these locomotives the motor is mounted on the locomotive-frame, which is carried on springs which transmit the weight to the journal boxes. The power is transmitted through connecting-rods to a jack-shaft that has its bearings in the locomotive-frame, and from the jack-shaft it is transmitted again by connecting-rods to the driving-wheels. The connecting-rods, of course, require counter-balancing, and this is done for electric-locomotive connecting-rods more effectively than it can be done for the cross-heads and connecting-rods of steam-locomotives, since in the case of the electric-locomotives the motion of all the connecting-rods and journals, etc., is circular in direction, and a circular movement is possible of complete balancing. In steam locomotives the motion of certain parts, like the cross-heads, is reciprocating and cannot be perfectly balanced. For this reason the balance of the connecting-rods on electric locomotives can be made more perfect than the balance of the connecting-rods and reciprocating-parts of steam locomotives.

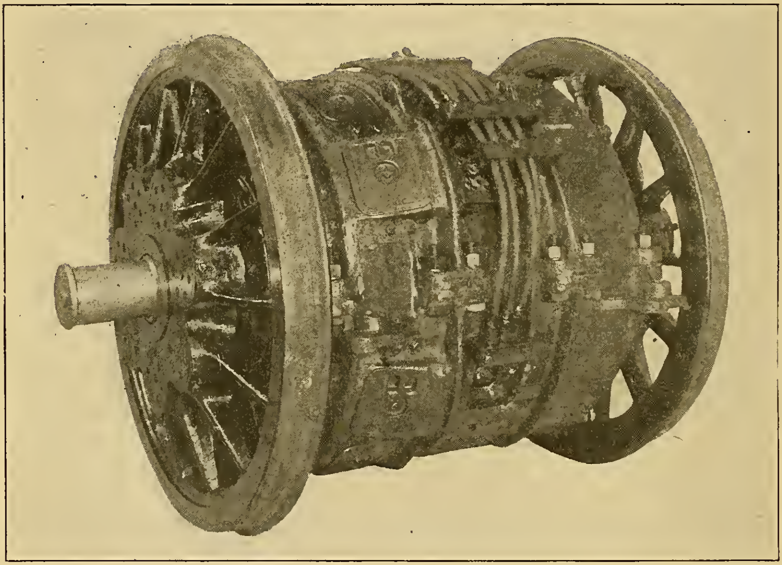

Fig. 7.—Single Phase, A. C. and D. C. Motor, Mounted on Locomotive Axle, Quill Suspension and Spring Drive to Main Driving Wheels.

THE CENTER OF GRAVITY OF LOCOMOTIVES SHOULD BE FAIRLY HIGH.

Regarding high and low centers of gravity in locomotives, experience has shown that locomotives, especially for high speed, should have the center of gravity high up. One of the reasons for this is apparent if we consider the effect of high speed on curved tracks. Consider what would happen if a locomotive could be built with a center of gravity so low that it was directly between the rails and therefore on a level with them. Such a locomotive could be run at high speeds without danger of turning over on curves even on a flat track. Whatever other results might occur, the locomotive would not tend to tip over, but would press against the outside rail on the curve in a horizontal direction, and this would tend to push the rail over, and if the rail would not turn over, it would tend to push the whole track over—ties and all—and the whole track has actually been moved on curves by locomotives of very low center of gravity running at high speeds. Now consider the case of a locomotive with a high center of gravity. Such locomotives when run at high speeds on curves tend to turn over. This is countered by elevating the outer rail, but still the tendency to turn over occurs on curves if the center of gravity is high, but with a high center of gravity the tendency to turn over throws the weight of the locomotive on top of the rail, pressing it down instead of pushing it out in a horizontal direction, as is the case where the center of gravity is low. It is manifest that a pressure on top of the rails will not spread the track or do the damage that a horizontal lateral pressure will cause.

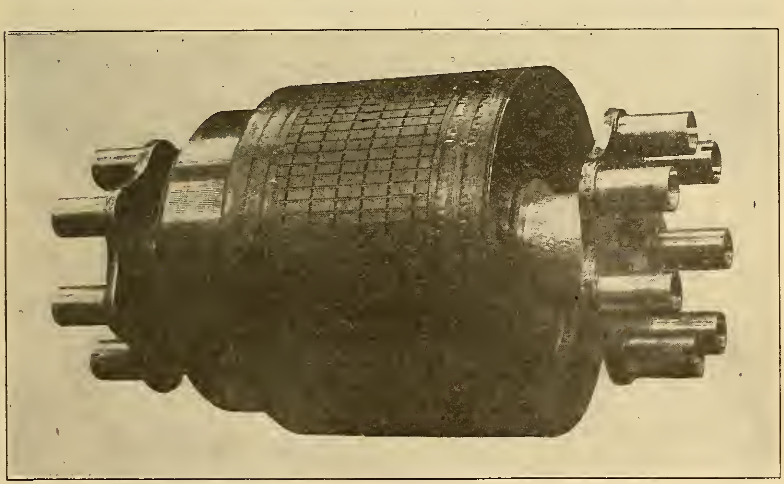

Fig. 8.—Armature of N. Y., N. H. & H. R. R., Single Phase, A. C. and D. C. Railway Motor, Showing Quill Construction.

The tendency of modern electric-locomotive design—especially for high speed operation—is toward a construction in which the dead or un-spring-supported weight of the wheels and axles is minimum and in which the center of gravity of the locomotive is high.

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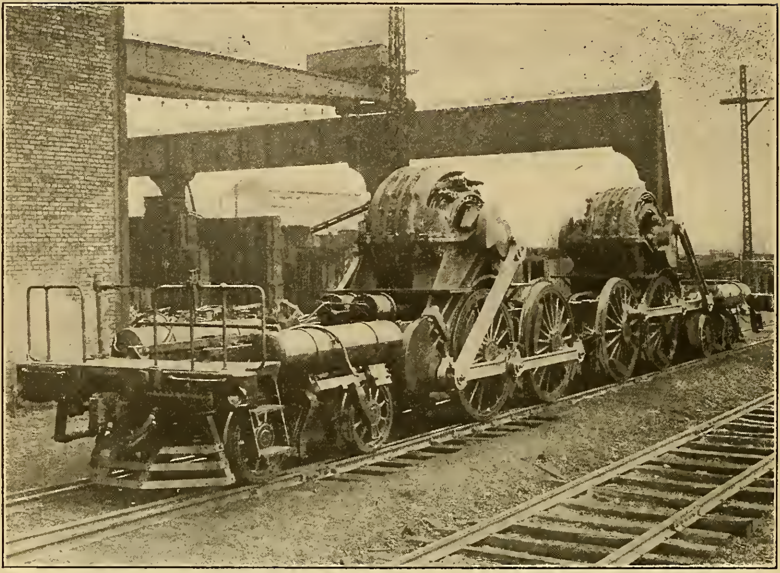

Fig. 9.—Pennsylvania R. R. Tunnel Locomotive (Cab Removed), Showing Mechanical Parts and Side Rods.

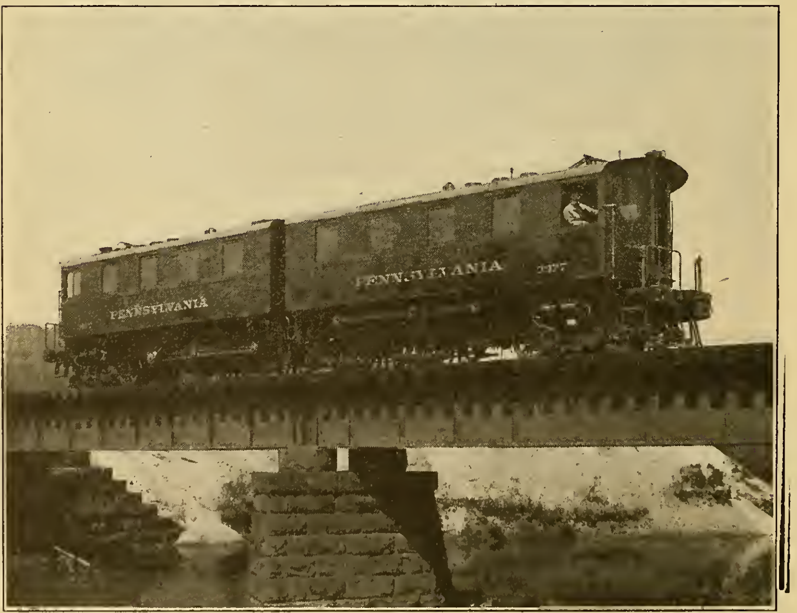

Fig. 10.—Pennsylvania T. and T. Co., D. C. Electric Locomotive, New York and Jersey City Tunnel Service.

GEARED VERSUS SIDE-ROD LOCOMOTIVES.

There has been considerable speculation and controversy regarding the relative merits of geared locomotives and side-rod locomotives for powerful machines. The New York, New Haven & Hartford Railroad Co. is going to determine this matter in a practical way. It has contracted for two very powerful moderate speed locomotives to perform equivalent work. One of these locomotives is already built and is in operation with gears. The other one is being built with side rods. The motors of the geared locomotive drive through quills, so that they add no dead weight to the axles and they are carried vertically above the axles instead of in the customary horizontal position, and therefore the motors are easily accessible and the center of gravity is higher than it would be if they were horizontal.

DISCUSSION.

Mr. G. T. Seely, M. W. S. E. (Chairman): The speaker gave a correct statement as to the saving in the operation of steam railroads by the adoption of electricity, and a case in point was the saving which was accomplished on the South Side Elevated Railroad when it commenced operating by electricity. The conditions are not exactly the same as in heavy steam-railroad work but still there is some similarity. The South Side Elevated Railroad was operated, in the beginning, with steam locomotives, propelling trains of two to five cars. In 1896 or 1897 it was one of the first roads operating *trains* of cars to adopt electric propulsion. At that time we were burning, in the day time, anthracite coal to prevent smoke. At night when the eye of the smoke inspector was a little dim we would mix in some bituminous coal; not because we wanted to get ahead of the smoke department, but because of the financial condition of the road, then in the hands of a receiver. Our coal cost on an average about $4.00 to $5.00 per ton. When electricity was adopted the amount of coal burned in the power-house was less in tonnage than the coal burned in the locomotives, and the cost, instead of being from $4.00 to $5.00 was less than $1.50 per ton. When burning 150 tons of coal a day it will be seen that a great saving was effected by the adoption of electricity. A saving was also made in the wages of the trainmen, but that would not be the case on steam railroads.

The cost per car mile of conducting transportation was reduced over one-third by the adoption of electricity over operation with the steam locomotives. The saving was a very considerable one and practically put the road on its feet.

Mr. W. L. Abbott, M. W. S. E.: I was much interested in some of the figures which were given, showing the distribution of the investment between the different parts of the standard electrical equipment of the road,—one-third to one-fourth to the power-house, about one-half for the distribution system, and the remainder for the equipment on the moving train. The fact at once becomes prominent that if, with existing systems, one-half of the entire equipment-cost of a road is required for the distributing-system and the moving machinery in substations, the advent of a new system which will greatly reduce the weight of copper required and eliminate entirely the moving apparatus in the substations must be an advent in electric railroading, whose effect will be noticeable in the near future wherever electric roads reach out and parallel steam roads. Those of us who are not in the railway business—either steam or electric—have been wondering at the apparent indifference with which the steam-road owners view the paralleling of their lines by electric roads. They affect to say that the electric road is merely developing a class of business which they—the steam roads—do not care to bother with, and that when the electric road grows to be of some importance they will buy it up and annex it. Such benevolent assimilation was recently witnessed in the case of the Western Union Telegraph Co. buying out the telephone company. The scheme worked the other way.

With the general adoption of high-tension distribution, feeding a great system of interconnected railroads, we can conceive of power-houses located at strategic points, such as coal mines and water powers, thus relieving the steam roads of the necessity of buying high grade coal and of hauling it to their coaling points. The possible saving of the cost of hauling locomotive coal taken in connection with the higher efficiency of a power-house on a concrete foundation as compared with one on wheels, is enough to make the difference between running a railroad at a profit and running it into the hands of a receiver. I believe it is regarded as inevitable, even by those who now operate steam roads, that all roads in territories where the traffic is as dense as it is within several hundred miles of Chicago must, within a comparatively short time, be operated by electricity, and from power-houses so widely separated that it will be necessary to use on the trolley wire higher voltages than are permissible within the city limits.

Mr. W. B. Jackson, M. W. S. E.: I have listened with much interest to this paper, as the matter of alternating-current traction vs. direct-current traction, which is in a way embodied in this paper, is unusually interesting, owing to the fact that eight years ago (I think it was) the Valtellina road that has been referred to in the paper was just starting. I had occasion to go over that road with considerable care. It is a three-phase road with cascade operation, and although the company that put in the equipment was having its troubles on account of its being quite a novel installation, yet it was one of the most perfectly operating roads that I think I was ever on as regards the starting and the stopping of trains. It seems to me that by no means should we feel that the last has been said about the possibilities of the three-phase traction. We have heard that the transmission system is a very important factor of alternating-current or direct-current railroads, and as our main-line railroads become electrically operated, the transmission system will become more and more important, owing to the very large quantities of power that must be transmitted great distances. In the case of the three-phase roads, we have the standard three-phase transmission, while with the single-phase roads we have the single-phase transmission. Also, as regards substations, it does not seem that there should be much difference between the three-phase and the single-phase, in that very large high-voltage three-phase transformers can be constructed, I believe, at not greatly increased cost over single-phase transformers. The distribution to the trains, although it may be necessary to use a lower potential, is on the three-phase basis and operates motors of the most reliable and satisfactory character which may be worked so as to be regenerative, although in the case of the Northern Pacific installation, which has been referred to, I believe the regenerative feature is obtained merely by operating the locomotives at a greater speed down-grade than their normal speed up-grade; consequently only a small part of the advantages of the regenerative feature is obtained in this installation. But it is entirely practicable to arrange installations so that the regenerative feature may be taken advantage of at all speeds above half-speed, and for all speeds above one-fourth speed, if the complications incident to such arrangement can be overcome suitably, so that breaking, at least down to half-speed, can be accomplished very well indeed by returning current to the trolley with the accompanying saving in power. When trains are slowed down to half-speed by returning power to the trolley, assuming appropriate equipment, it is almost impossible to tell just when the train is slowing down except when standing up in the car so that the reduction in speed may be felt through inertia. All things considered, I am not at all certain but that three-phase traction may eventually work in as a far more important element in long-distance railroading than present conditions indicate.

Mr. A. P. Jenks: I do not know that I should consider myself qualified to discuss Mr. Darlington's very interesting paper, as my work for the past few years has been more along commercial lines than engineering; at the same time I have tried to keep up-to-date in electric railway development as to both high-tension alternating-current and direct-current systems. As pointed out in Mr. Darlington's paper, the respective systems have their strong advocates, and probably always will as long as they exist, and I judge from Mr. Darlington's talk and his paper that he is one of the strong advocates of the single-phase system and has rather neglected the high-tension D. C. system. I desire to take exception to a few of his statements in comparing the single-phase high-tension system with the direct-current. I believe he states in his paper, which I have not carefully read, that the initial cost of the single-phase is far cheaper than either the 600 or 1200 volt D. C. systems. Of course, local conditions have to be taken into consideration and that is a rather broad statement to make. It may be true under certain conditions. Under other conditions the reverse would be very likely true. I think, for comparatively short roads operating a large number of cars with frequent service, that the 600 volt D. C. system will give a lower first cost than the single-phase system. I have recently seen a number of very interesting engineer's reports, carefully prepared, showing that the 1200 volt D. C. system is just as cheap in first cost as the single-phase 6600 volt system for what you could call interurban roads in length from 25 to 50 or 75 miles. As Mr. Darlington states, the difference in cost between the single-phase and the direct-current, presumably on the basis of 600 volts D. C., is largely in the distribution system, being in favor, of course, of the single-phase, but that difference, when the voltage is raised to 1200 or higher, disappears almost entirely in the cost of the overhead copper. We then have the excessive cost of the very expensive single-phase motor-equipment compared with the extra cost of the direct-current rotary-converter substations, and I think it will be found for the average interurban railway that these two items will about offset each other, leaving an even balance for the total initial investment.

With reference to the operating cost, again Mr. Darlington infers that the single-phase system is much cheaper than the direct-current system, due to the absence of substations in the former system. That is true to the extent that they have not that expense. But on the other hand, it has been shown—and I have seen reliable data obtained from roads that have operated with both single-phase and 1200 volt D. C.—that the maintenance cost of the single-phase motor-equipment is much higher than the direct-current equipment, which more than offsets the extra expense of substation maintenance, and there are other important factors that make the 1200 volt D. C. system much more attractive from an operating point of view.

I am not bringing out these points in the nature of a criticism of the single-phase system because I believe that the single-phase system has its merits, but I also think that the high-voltage D. C. system, which has been developed since the single-phase was brought out, is coming to the front rapidly—is here, in fact—as there are a dozen or more roads now operating with this system. It has the advantage of the low initial cost of the single-phase and none of the latter disadvantages as applied to the average interurban trolley road.

Trunk-line steam-railway service is a different condition and must be studied carefully. I think the possibilities of higher direct-current voltage—1800 to 2400 volts—will probably put it on an equal basis with the 11,000 volt single-phase system.

Another point that I wish to bring out is that the 1200 volt,

D. C. system permits of using standard D. C. apparatus. The railway motors are either standard 600 volt motors, insulated for 1200 volts, or wound for 1200 volts, which is made possible by the introduction of the commutating pole motor; 600 volt 25 or 60 cycle rotary-converters can be run in series, or built for 1200 volts, and there is no difference in the operation of the high-voltage D. C. system and the so-called standard 600 volt system. The simplicity and familiarity with such a system is a very important factor in its favor, I should think, from an operating standpoint, and furthermore, it enables the railroad companies to utilize 25 cycle or 60 cycle current, with the resultant advantage of being able to furnish power for lighting or industrial purposes. To get the full benefit of the single-phase equipment, it is necessary to go to lower frequencies, such as 15 cycle, which would mean special apparatus throughout.

Mr. A. Bement, M. W. S. E.: I have a word to say. It is relative to the appreciation shown by the public for electric service, which includes electric transportation service. I think it is a very important factor, but I do not think an attempt has been made to determine a value for it, but it has, I consider, a large value. We see this illustrated in the case of trolley lines that parallel steam railroads. They take from the steam railroad a large part of the business which formerly waited for the arrival of the steam trains; they also take another large percentage of the business from the steam trains, even when the steam trains are waiting to take the passengers. This is well illustrated in the vicinity of San Francisco. Communication across the bay from San Francisco to Oakland, Berkeley, and Alameda is by ferry. There are two transportation lines,—the Southern Pacific with steam service, and the San Francisco, Oakland, and San Jose, which is an electric line. These lines parallel each other as to accessibility, frequency of trains, and in all other respects they are in duplicate, except that one is operated by steam and the other by electricity. They gather their passengers in the same manner and deliver them at the head of long piers, from which point they go by ferry-boat across the bay to San Francisco, all arriving at the same ferry-house. Likewise, in leaving the city, passengers leave from the Market Street ferry for their homes in the cities across the bay. In fact, in one respect the Southern Pacific has an advantage over the electric line, as its ferry-boats are equipped with a restaurant, while boats of the electric line are not. Notwithstanding the fact that the service afforded by the steam line could be considered equal to that offered by the electric line, the latter trains handle practically all of the suburban passenger traffic up to a point where the congestion on the electric line causes an overflow to go to the steam trains. The Southern Pacific Railway is planning now to electrify its suburban service so that it may compete with the San Francisco, Oakland, and San Jose Railway, which is popularly known as the Key Route.

In reference to the low center of gravity in locomotives, in addition to its tendency to exert a force on the rail tending to push it out of place, it causes excessive wear of both wheel flanges and rail heads.

Mr. E. N. Lake, M. W. S. E.: I would call attention briefly to two subjects which to my mind have not received, in the paper of the evening, the attention which it seems to me their importance requires. These are *standardization* and *interchange.* Let us think for a moment of the steam-road engineer who approaches this question of electrification. He sees in the printed paper here the simple statement that there are three systems of electrification,—the direct-current, the single-phase, and the three-phase. But from the standpoint of interchange instead of three systems, let us see how many there are. You may subdivide the direct-current system into the principal divisions of 600 volt and 1200 volt. You may further subdivide the system as to working conductor into an overhead trolley and the third rail. Then there is the modification of gearless and geared motors, connecting-rods, and all that class of variation in design, all of which affect clearance, presumably. Then when we take up the single-phase system and consider, say, fifty-four existing railroads which have a mileage of 1700 or 1800, and a total motor horse-power of say 200,000, about equally distributed as to number of roads between America and European countries, we find that there are a large number of variations in this system. For instance, we notice that in our own country there is a difference in the matter of catenary, single-catenary, and double-catenary. There are at present seventeen different voltages in operation on single-phase systems, ranging from 500 volts to 20,000 volts. Some railroads have two or three voltages on the same system. There are seven different frequencies in operation at the present time, ranging from 15 cycles to 42 cycles, so that, as a matter of fact, from the standpoint of interchange instead of three systems there are nearly thirty-three. These questions of standardization and interchange must be worked out, must be reduced to their simplest terms, before we can expect that electrification will make its strongest appeal to the steam railroad people. The history of railroad development has been first the development of isolated lines and systems. Electrification seems to be following along the same path. We have isolated electrification systems for city terminals, at tunnels, and at such locations as that; but electrification will never make its appeal to the trunk-line proper until these questions of interchange and standardization have been worked out.

There is one question I would like to ask and that is as to a new design of the catenary construction,—what the working conductor would be, whether it would be part copper and part steel wire, or all copper or all steel.

Mr. Seely: A point in favor of these different systems is the fact that we have them, and the enthusiastic supporters of each system brings about an advance in the art; with the present state of the art, if we did not have this competition there would not be as much advance made.

Mr. George H. Lukes, M. W. S. E.: One thing occurred to me in listening to Mr. Darlington's paper, and that is the difference in the attitude. This perhaps illustrates the progress of electrification of steam-railroads. Several years ago we had a meeting which was addressed by a prominent engineer from one of the manufacturing companies, on the electrification of steam-railroads, and, as I remember it, throughout his talk he was very careful to say that electrification was applicable to special conditions only. He was very careful not to say it was applicable to all conditions. He spoke about electrifying certain divisions on trunk lines—mountain divisions where the traffic had outgrown the capacity of the steam equipment. Tonight I notice that Mr. Darlington does not seem to be at all alarmed at the idea of electrifying ordinary steam railroads, which I think illustrates that there has certainly been a great advance in the last two or three years.

Mr. C. Renshaw: The author states in his paper—and it seems to be the keynote of the matter in regulating the discussion—that it was not his object to bring out the desirability or the economy of electrification as compared to steam, but to present the problem as to which of a number of available systems was most suitable to the general problem of electrifying steam railroads.

The Baltimore tunnel was equipped with electric locomotives in 1893. As far as the locomotives alone were concerned, engineers were entirely capable of electrifying steam railroads at that time, but no such electrification was then undertaken other than that of tunnels or terminals, because, although motors were then available, a suitable transmission system was lacking. For the same general reason trolley roads were built paralleling steam lines all over the country rather than the electrification of the steam lines themselves taking place. The men in charge of the steam railroads felt that the electric system—particularly the transmission system—that was available was not suitable to their conditions. They could have electrified their lines and operated over them single cars, light cars, of the same character that were used by the trolley roads which paralleled them, but they all seemed to feel that this was not the solution of their problem. Any system of that nature which they might put into operation would be temporary and would sooner or later have to be replaced with a system which could handle not only single-car operation but train operation; which could handle not only a passenger but also a freight business; and it was not until the development of the alternating-current systems that any system was made available for the use of the steam railroads which enabled them to electrify their lines on a permanent basis. The development of the high-tension alternating-current system has now, brought about that condition, and electrification has reached a point where any steam road can electrify any length of line that it sees fit; not merely a tunnel, or a terminal, or a short stretch where suburban travel is heavy, but any portion of the road; any length of line that seems desirable can be electrified on a basis which will enable it to handle any kind of traffic that steam-power can handle, and to do so with a reasonable investment as far as first cost is concerned and with a reasonable operating expense.

The original electrification of trolley roads required the construction of a power-house and of the trolley line; also the purchase of some cars to run over that line. The power-house was able to feed the entire system directly without any intermediate link. Now, for ordinary distances the single-phase system has put the steam railroad on exactly the same basis. By the use of 11,000 volts on the trolley, a steam railroad can electrify a reasonable distance and simply feed from the power-house, directly into the trolley line, with no other link between the generation of power and its utilization at the car. The electrified portion of the New York, New Haven, and Hartford Railroad, for instance, is operated in this way. It consists of a stretch of 22 miles and the entire 22 miles is fed in the simple, old-fashioned way of the trolley road. The generators are connected directly to the trolley wire, and the latter supplies the locomotive.

By simple extension, the 22 miles could be easily extended for three times its present distance with essentially the same simplicity. Two transformer-stations located 30 miles each way from the power-house could each supply a 22 mile section (no attendants would be necessary at the transformer stations or anything of that sort) and 66 miles could thus be operated with the same general simplicity as the present 22 miles is operated.

In a certain way it may be said that a three-phase system would offer equal facility for electrification, were it not for the fact that the three-phase system requires a distributing-system, as Mr. Darlington brings out, which is very much more complicated than the single-phase; it requires substations oftener than the single-phase, and requires these substations to be more complicated; in general, it runs up complications of that sort so much, that except for special service it hardly seems desirable.

The matter of interchange of equipment and standardization, which one of the previous speakers called attention to as being a vital point as far as steam railroads are concerned, can be solved at once by the 15 cycle, 11,000 volt, alternating-current system. As far as any question of satisfactory operation and features of that sort are concerned, such a system could be adopted today and be adopted as an absolute standard. Any railroad in the country can electrify its lines with this system, and be absolutely sure that the system can be extended indefinitely to cover any kind of steam railroad service that is in operation today.

It is true, as one of the speakers has said, that the single-phase roads that have been put in, considering the trolley roads also, have been put in with a wide range of voltages and with a slight range in frequencies, but considering the steam railroad electrifications proper, the range has not been nearly so great. Three different steam-railroad electrifications have been put in on exactly the same basis. The New Haven Railroad has been put in with 25 cycle, 11,000 volts. (This is the largest and most important.) The Erie Railroad (a portion of it) has been put in on the same basis,—11,000 volts and 25 cycles. The Denver and Interurban road, which is an electrification of the Colorado Southern, was put in on exactly the same basis—11,000 volts and 25 cycles—and, in general, these conditions have been to a certain extent standardized at the present time for steam-railroad electrifications. What has been done in the way of electrification now, however, is only a drop in the bucket, and it has become evident that in looking forward to electrification on a large scale, 15 cycles at the same tension of 11,000 volts has some advantages over 25 cycles, but as far as this matter is concerned, 25 cycles would give an entirely practicable system; the steam-railroads of the country could be economically and satisfactorily electrified today with this one particular system that has been put in service, if necessary, and every kind of traffic that is handled today by the steam locomotives could be handled in this way.

The reasons which make the single-phase system so satisfactory are of course familiar, in a general way, to all, but possibly by quoting a figure or two I can bring out the vital point in a way which will be more likely to be remembered.

If we consider an ordinary trolley construction of single track, 70 pound rails, and 000 trolley wire, for direct-current, there will be a drop in voltage of about 33 volts per 100 amperes per mile. If one undertook to transmit 100 amperes for 10 miles over such a line, there would be a drop of 330 volts, and if the line was being supplied at 600 volts, there would be left 270 volts at the distant end of the line, which, with 100 amperes, would mean 27 kilowatts. It would also mean that there was a loss of 55%. But in transmitting power with 25 cycle alternating current, at 11,000 volts, over the same circuit there would be a drop in voltage of 60 volts per 100 amperes per mile, and an energy loss of about 60% of that, or 36 volts, and in transmitting the same current of 100 amperes for 10 miles there would be 600 volts drop and a loss in actual energy corresponding to 360 volts lost. That 600 volts drop in this case, however, with 11,000 volts supplying the line, instead of being 55% drop would be only 5.5% drop, which would be entirely insignificant as compared with the drop in the other case. Moreover, supplying 100 amperes at 11,000 volts, 1040 kilowatts would be transmitted instead of 27. In this way a startling difference will be noted between using 11,000 volts on a trolley line in transmitting power, as compared with using 600 volts or even 1200 volts.

From the same figures it can be seen that one may transmit power at 11,000 volts for 100 miles with only the same percentage drop which was obtained in transmitting 10 miles with 600 volts.

One significant fact has impressed me very greatly in considering the matter of real trunk-line electrification. Practically the only real trunk-line electrification that has been put into effect, where any length of railroad has been electrified for other purposes than the mere carrying of trains through a tunnel or handling a strictly suburban traffic, is that of the New Haven road. Of course, the suburban traffic of the New Haven road is fairly heavy, but there are a large number of other trains handled over that section also. This one trunk-line which has been electrified on a large scale with the single-phase system is the only trunk-line which, after having been electrified, has been so satisfactory that the management has considered extending the electrification. The New York Central R. R., which is often compared with the New Haven system, is only just now completing the plans originally made for electrification, and, as far as has been published, no intimation has been made that they would ever carry that electrification to any point beyond the limits originally laid out.

The New Haven road, on the other hand, is making active plans to carry its electrification further, and to carry it the whole distance from New York to New Haven. This would considerably more than double the portion of the line which is now operating electrically. As showing the interest that the New Haven road is taking in this matter, they have since equipped an additional mile of road with a slightly different form of catenary trolley construction—a somewhat cheaper form—which was worked out as being the proper kind of construction to use when they did carry their line on to New Haven, and they put up this mile of it, in order to see how it would work out in actual practice, and to get ready for quickly carrying the work further in the near future, when the time seems ripe. They have also been making very careful study with regard to operating their freight trains electrically, and the Westinghouse Electric and Manufacturing Co. is supplying to them two different types of electric freight-locomotives. Each of these is capable of handling a 1500-ton freight-train, which is as heavy a train as is ever operated over their road. One of these locomotives has been tested at the works, and has been tested on the New Haven road, and has actually handled a 2200-ton train, starting it up from rest and pulling it out of a siding, which had a very sharp curve leading into the main track. It is a most impressive sight to see an electric locomotive take hold of a train of this sort—so long a train that it is quite a task to walk to the end of it—and pull it along, quietly and easily, with the sole source of its power from a little wire hardly any thicker than a man's finger. To see that done is one of the most convincing arguments that can be presented in favor of the high-voltage, alternating-current, single-phase system.

An incidental, but nevertheless an important advantage of the single-phase system is the fact that on account of the long distance over which power can be transmitted at high voltage, a single unit—either a power station unit or a substation unit—can handle a much longer stretch of track than could otherwise be handled, and consequently with trains widely scattered this unit can be kept more uniformly loaded. If a certain substation can cover only a limited section of track, then of course that unit is going to be running a much greater part of the time at light load than would be the case if it should cover a longer section of the track, because, regardless of the character of the service, it is only reasonable that the longer the section of track considered the more uniform will be the load on that section.

The single-phase system is able to handle any kind of traffic that the steam locomotive can handle. This will enable the railroads to carry out electrification in piecemeal if they desire, and yet have something permanent when they get through with their work. For instance, a terminal line of twelve or fourteen or twenty miles or so can be electrified for immediate use in handling suburban traffic. The same system can handle freight traffic over that section, or can handle heavy through-trains over that section, with equal facility, and consequently all trains running over the section for any purpose can be readily handled by the system which is installed. If a direct-current system were put in, although it might be admirable for handling the suburban service, it would be at a disadvantage in handling the heavy-train service and would be at a most decided disadvantage if it were necessary to add a more distant link in connection with it.

With reference to the matter that one of the speakers brought up, considering, of course, trolley roads rather than steam railroad electrification, since there has been no steam-railroad electrification using 1200 volts direct-current, it is hardly proper to speak of 1200 volt apparatus as being absolutely standard, because, although 1200 volt equipments can be run on 600 volts, 600 volt apparatus of the ordinary sort most certainly can not be run over the 1200 volt lines. Better insulation is required for 1200 volt apparatus, and to secure room for this a motor of a given horse-power capacity for operation on 1200 volts takes, ordinarily, the next larger size of frame than is required for 600 volts. The control apparatus also has to be better insulated and laid out for 1200 volt work.

In regard to the cost of maintenance being high on single-phase apparatus, this is not necessarily the case. The speaker may, of course, have gotten his figures from specific instances where the cost was high; but to show that the cost is not necessarily high, I might say that I had occasion to go over the books of one of the largest single-phase trolley companies—and one of the first ones also, for that matter—the Indianapolis & Cincinnati Traction Co., and in going over their books very carefully for the year 1908 it developed that the cost of maintaining the electrical equipment of the cars was less than is the cost on a great many direct-current roads. Actually, it figured out something less than 0.75c per car mile. I have known of 600 volt, direct-current roads operating on a basis that was fairly comparable with this single-phase road, in which the maintenance of electrical equipment cost considerably more than this figure.

In regard to the matter of using 60 cycle current for conversion into 1200 volt direct-current, it is, of course, just as easy to convert 60 cycle current into 15 cycles or 25 cycles by means of a motor-generator set as it is to convert it into direct-current, especially into 1200 volt direct-current, for although one might use 60 cycle rotary-converters for converting 60 cycles into 600 volt direct-current, I have never heard it proposed to connect 60 cycle rotaries in series for producing 1200 volts. Even if this should be done, a great many people, particularly on the Pacific Coast where 60 cycles is prevalent, use motor-generator sets even for obtaining 600 volt direct-current for railway work, and they consequently could just as well obtain 25 cycle or 15 cycle alternating-current in the same way as they obtain direct-current of either kind.

Mr. G. W. Brady, M. W. S. E.: I wish to ask if the New Haven road is still operating the third-rail branch they used to have some years ago, and also what the power-factor was on the A. C. line where this compensating winding in the single-phase motor is being used.

CLOSURE.

Mr. Darlington: I am very much gratified with the general agreement with what I have said, and am glad that two or three points have been brought out which I deem of equal importance to anything that I have said.

I am going to speak of these questions in the reverse order to that in which they were brought up.

The power-factor on the New Haven road on the alternating system with 25 cycles is not so good as it would be with 15 cycles. It ranges generally between 80% and 85%. Of course, the power-factor is not a very important item. A lower power-factor simply means that the transmission lines and trolleys, etc., should be slightly larger. The size of these is largely a question of voltage.

Somebody asked whether with new construction steel or copper would be used for the contact wire. I think there is no objection whatever to running on a copper wire unless one is running at very high speeds, where there is liability of breaking the contact wire at the point of support. Copper is perfectly proper up to fifty or sixty miles an hour, and steel would be unnecessary for lower speeds.

The question of standardization and popularization of railroad service by electrification are both matters of prime importance. I did not mention them because I could not cover the whole field. We all appreciate that if the railroads of the country are going to be electrified generally, there must be a standard system just as a standard track-gauge is needed for all railroads. They will all have to use one electrical system just as they all have to have a uniform track-gauge. The popularity of electric power is one of the great things that has led to the development of trolley-road service. People prefer to ride on electric roads wherever trolley roads are available, not only because it is nicer on the cars, but also because trolleys stop on the street corners, run over the city streets and take them where they want to go,—all of which features operate in their favor.

One of the speakers evidently misunderstood the purpose of my paper, for he has overlooked in his discussion the features that I tried to bring before you. The matter of 1200 volts versus single-phase has been much discussed, but 1200 volts has been talked of almost entirely as applied to trolley roads. I have been trying to talk to you about the electrification of existing steam railroads, not trolley roads for operating a single car or for operating at most two or three cars on a uniformly distributed schedule. Wherever 1200 volts has been used it has been on trolley roads. I have tried to avoid talking about what may hereafter be done with electric power, except where practical applications have demonstrated the results that may be secured with direct-current, or with three-phase current, or with single-phase current. There are no heavy railroad electrifications with direct-current except at terminals and for short distances. Ordinary railroad trains are heavy trains; they are generally more than two or three car trains and they are not distributed on even schedules half hourly or hourly, as is customary with trolley roads.

A very excellent paper was published by Mr. C. E. Eveleth in the transactions of the Philadelphia Branch, A. I. E. E., on the 1200 volt interurban railways, in which is given the cost of 1200 volt electrification, but Mr. Eveleth gives the cost of 1200 volt electrification only for light railroad service, the heaviest being for three-car trains, on an evenly distributed service. That means 1200 volt costs are estimated by Mr. Eveleth for trolley roads operating three-car trains. When his figures are examined it will be found that they give the total cost of power transmission and distribution apparatus for 1200 volts, including the transmission line, the sub-stations, and the third-rail, but without third-rail feeder of copper wire, close to $14,000 per mile of single track. If one were to electrify with 1200 volts for heavy railroad service, the cost based on those calculations would go still higher—to $15,000 or $20,000 a mile without any question—and these are the best figures I know of that have been published. We cannot put such a tax on the steam railroads and expect the savings by electrical operation to pay interest, operating-expenses, and fixed charges on the electrical equipment. Furthermore, say what you will about 1200 volts, there is still the substation operating-expense which is a heavy cost that is not required for alternating-current traction. In standardizing, there must be something that will do not only for the trolley roads but for steam railroad electrification, and something that will not cost $14,000 or more per mile for apparatus to get the current from the power-house to the moving trains.

In the matter of the power plant. That is a very interesting subject and one I would like to talk about, but will say only this: When railroad electrification gets to be general, it will start in fairly populous districts, and without any question economy of operation and construction will determine that the power-plants will be, as Mr. Abbott said, at strategic centers, in places where a power-plant can be built to serve a large number of trains, a long mileage of track, utilize cheap coal, and secure a fairly even load-factor by distributing electric power to a large number of trains. I predict when railroad electrification gets to be general in this state of Illinois, there will be three or four big power centers in the state that will be selling power to railways, and big electric power-plants will be built that will furnish power over a great many miles, and sell power to different railroads and also to all sorts of manufacturing and industrial enterprises.

Referring now to Mr. Jackson's remarks, it is true, as he remarked, the last has not been said about three-phase traction. There are places where three-phase current has advantages. A bad thing against it, however, is the question of standardization. In order to make the three-phase system generally acceptable it must be capable of being standardized. To be standardized it must be suitable for high speeds; it must be suitable for low speeds; and for frequent starting, stopping, and accelerating, and most of all it must be economical. Three-phase installations do not meet all of these conditions as well as single-phase for average railroad requirements.

Mr. Jackson spoke of a trolley road in Europe which has three economical operating-speeds. How do they get them? They have a motor for one speed; at another speed they have another motor, and at another speed they put the two in together. That is not an economical condition.

I take exception to Mr. Jackson's statement that three-phase transformers can be built as cheaply as the single-phase. In general a three-phase transformer is more costly than a single-phase transformer of the same capacity, and this is especially true in the case of very high voltages. The winding of a transformer goes up in cost very rapidly as the voltage increases, and the winding of three-phase transformers is more costly than for a single-phase transformer of the same total capacity. Railroad electrification is a question of getting a system that is suitable for standardization for all kinds of work, keeping the point of economy in view.

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